AFFTC-TIM-07-02

F-16B PACER AIRCRAFT TRAILING CONE LENGTH EXTENSION TUBE INVESTIGATIVE STUDY (HAVE CLETIS)

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AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
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This Technical Information Memorandum (AFFTC-TIM-07-02), F-16B Pacer Aircraft Trailing Cone Length Extension Tube Investigative Study (HAVE CLETIS), was submitted under job order number M07C0400 by the Commandant, USAF Test Pilot School, Edwards AFB, California 93524-6485.

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EXECUTIVE SUMMARY

This technical information memorandum presents the calibration results for the Air Force Flight Test Center (AFFTC) F-16B pacer aircraft modified with trailing cone systems of four different lengths. The responsible test organization was the 412th Test Wing, AFFTC, Edwards Air Force Base, California. Testing was conducted under job order number M07C0400. All testing was conducted at AFFTC, Edwards Air Force Base from 5-26 March 2007 and consisted of nine flights totaling 17 flight test hours. This test was a follow-up to testing completed during the test program which used a 50-foot fixed-length trailing cone system. Pressure measurement inconsistencies were noted during that testing which motivated testing of different trailing cone system lengths.

The trailing cone system was attached to the tip of the vertical stabilizer; system length was defined by the distance between the attachment point on the aircraft vertical stabilizer and static ports ahead of the trailing cone. The trailing cone system measured static air pressure using pressure tubing trailed behind the aircraft. The goal of this test program was to evaluate four different system lengths (35-foot, 50-foot, 65-foot, and 85-foot) and to determine which system provided the best balance of trailing cone flying characteristics and data quality.

Each of the four trailing cone systems was evaluated for airworthiness and stability. Regions of instability within the trailing cone flight envelope were identified during a dedicated flying qualities sortie for each length. The cone flying qualities testing covered a matrix of test points that built up in Mach number and incompressible dynamic pressure between 2,500 and 30,000 feet pressure altitude and up to 0.95 Mach number. During cone flying qualities testing, cone deformation was observed for several cones at high incompressible dynamic pressures. Cone deformation prevented tower flyby evaluation of the 35-foot and 85-foot trailing cone lengths.

After the cone flying qualities sorties were complete, each system length was to be tested in a series of tower-flybys to determine the static source error corrections. Tower flybys were only completed for the 50-foot and 65-foot trailing cone systems and were limited to lower Mach numbers because of cone deformation during other sorties. The tower flybys were flown at approximately 150 feet above ground level at speeds between 170 KCAS (11 degrees angle of attack) and 525 KCAS (0.82 Mach number at 2,400 feet pressure altitude).

Overall, the 50-foot trailing cone system attained satisfactory flying qualities, equivalent static source error correction variance to the 65-foot system, and sustained less system damage on takeoff and landing than the other lengths. However, due to the limitations specified in this report it was impossible to draw a firm conclusion on which trailing cone system was the best. Further flight testing is recommended to establish a clearly optimal trailing cone system.

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BACKGROUND

This technical information memorandum presents the trailing cone system calibration results for the Air Force Flight Test Center (AFFTC) F-16B pacer aircraft, USAF serial number 92-0457. The responsible test organization was the 412th Test Wing, AFFTC, Edwards Air Force Base, California. Testing was conducted under job order number M07C0400. All testing was conducted at AFFTC, Edwards Air Force Base from 5-26 March 2007 and consisted of nine test aircraft flights totaling 17 flight test hours.

Previous F-16B trailing cone testing was accomplished with a 50-foot trailing cone system; results of this testing exhibited an oscillation in pressure readings that contributed to the overall uncertainty of the trailing cone system. This was possibly due to the effects of the aircraft's pressure field. The pressure measurement oscillations motivated the testing described in this report to determine a trailing cone length least influenced by the aircraft.

The program chronology is found in the Test Log, appendix A.

TEST ITEM DESCRIPTION

The AFFTC pacer aircraft was an F-16B, two seat fighter aircraft, USAF serial number 92-0457, with a block 15 airframe, block 30 wings, and block 25 landing gear. The fuselage was characterized by a large bubble canopy, forebody strakes, and an engine air inlet located under the fuselage. The aircraft was powered by a single F100-PW-220 afterburning turbofan engine with maximum thrust of approximately 23,000 pounds. The aircraft was flown with a 370-gallon external fuel tank on both wing stations 4 and 6. For a complete description of the F-16B, refer to the F-16B Flight Manual and the F-16B Supplemental Flight Manual, references 1 and 2.

The special instrumentation on the F-16B test aircraft used the production F-16B noseboom-mounted air data probe to collect data for both total and static pressure systems. The air data probe incorporated a single Pitot port and two separate static ports comprising two semi-independent Pitot-static systems numbered "one" and "two". Each of the Pitot-static systems was connected to calibrated Dual Sonix® pressure transducers. The sensitive transducers provided input signals to the Advanced Airborne Test Instrumentation System which output to the test aircraft cockpit displays, a PC/104 flashcard memory, and a Multi-Application Recorder/Reproducer digital recorder. The production and special pacer air data systems and data acquisition system are discussed in the Detailed Test Item Description, appendix B. A G-Lite differential GPS receiver/recorder was installed in the aircraft to provide time-space-position information as an additional source of truth location information. The parameters available from the G-Lite are listed in table B-2.

A fixed-length trailing cone system was installed on the aircraft for the dual purposes of providing pressure data for use in calibrating the pacer noseboom system and for use in directly calibrating the air data systems on other test aircraft. The system consisted of an

anchor fixture, a pressure transducer, Nylaflow® pressure tubing reinforced with a steel cable, a heat-resistant Kevlar® fire sleeve, a stainless steel static pressure sensing sleeve with skids positioned behind the pressure ports, and a drag cone (figure 1). The system was attached to the aft tip of the vertical stabilizer in the location of the radar threat warning system. Four different trailing cone tubing lengths were tested: 35, 50, 65, and 85 feet. The tubing length was defined as the distance between the anchor fixture attached to the aircraft and the static sleeve in front of the trailing cone. A detailed description of the trailing cone system is found in appendix B.

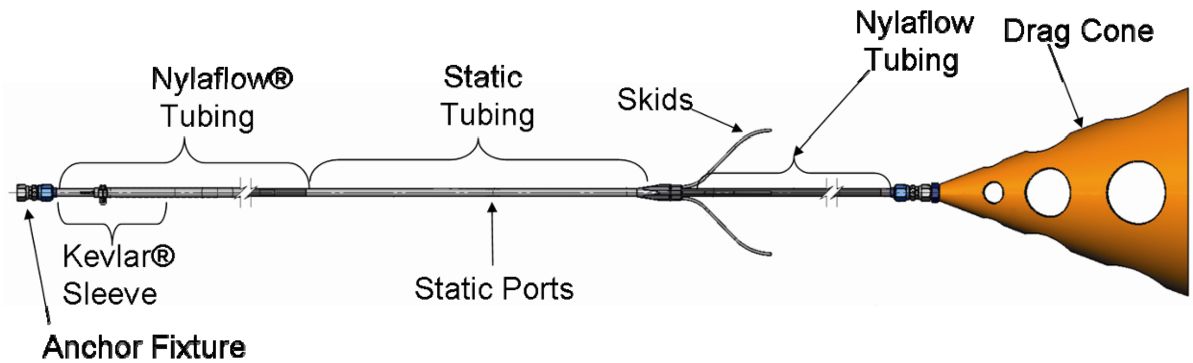

Figure 1. Trailing Cone Assembly

Operational procedures for the test aircraft air data system and the trailing cone system are presented in the F-16B S/N 92-0457 Modification Flight Manual, reference 3.

TEST OBJECTIVES

The test program goal was to evaluate four different trailing cone system lengths and determine which length provided the best combination of trailing cone flying characteristics and data quality. The test objectives were:

1. Evaluate the flying characteristics for the trailing cone system.

2. Collect trailing cone data for use in calibrating the noseboom.

3. Determine the trailing cone static source error corrections.

4. Determine the relationship between the trailing cone system length and the pressure altitude oscillations of the system.

5. Evaluate the temperature profile along the Kevlar® sleeve during test operations and compare these values to the melting temperature of the Nylaflow® tubing.

6. Observe damage to the static sleeve skids and the Nylaflow® tubing.

LIMITATIONS

The test objectives were not fully met for the reasons outlined below:

- Drag cones exhibited structural deformation under high incompressible dynamic pressure during four sorties.
  - The 50-foot and 65-foot system tower flybys were limited to lower Mach numbers to prevent cone deformation.
  - Two different drag cones attached to the 85-foot system deformed on the two sorties attempted. Additional drag cones were not available; therefore, the cruise flying qualities evaluation and tower flybys were not completed for this system.
- The 35-foot system flying qualities evaluation and tower flybys were not completed because of damage sustained to the Nylaflow® tubing.
- The PC/104 data system failed during the 65-foot trailing cone flying qualities sortie; therefore, only qualitative observations of trailing cone flying qualities data were recorded.

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TEST AND EVALUATION

The trailing cone flying qualities sorties and tower flyby flights were conducted from 5-26 March 2007. Testing consisted of nine test aircraft sorties encompassing 17 flying hours. Testing was accomplished using F-16B USAF serial number 92-0457. Six F-16B chase support sorties were flown for an additional 9.5 flying hours.

OVERALL TEST OBJECTIVE

The goal of this test program was to evaluate four different trailing cone system lengths and determine which length provided the best combination of trailing cone flying characteristics and data quality.

The test results were considered to be satisfactory if a consistent, minimally variant static source error correction could be discriminated amongst one of the four system lengths and if that particular system's pressure altitude oscillations were acceptable for use as a calibration truth source.

The test objectives were not fully completed as mentioned in the Limitations section; trailing cone flying qualities and tower flyby data that were collected and are shown in table 1. These data allowed the test team to make only qualitative conclusions about the cone flying qualities for the 65-foot trailing cone system and only make a comparison of the static source error corrections from tower flybys for the 50-foot and 65-foot lengths.

Table 1. Flying Qualities and Tower Flyby Data for Each Trailing Cone System Length

	Pressure Altitude (feet)				
System Length (feet)	30,000	20,000	10,000	2,500	2,100-2,500 (TFB)
35	✓	✓	✓	×	×
50	✓	✓	✓	✓	✓
65	-	-	-	✓	✓
85	✓	✓	✓	✓	×

✓ Qualitative and quantitative data
- Qualitative data only (due to data system failure)
× No sorties flown (due to cone structural deformation)

PRESSURE AND TEMPERATURE SENSOR CALIBRATION

A Setra model 370 pressure transducer, Druck DPI-145 digital pressure gauge, NovaLynx 230-355 pressure altitude indicator, and two Omega HH40 series thermometers were used to measure the ambient air pressure, pressure altitude, and ambient air temperature at the flyby tower. A Paroscientific pressure transducer, model number 6000-15A, part number 1601-002, serial number 97609, was used to measure in-flight static pressures from the static sleeve ports of the trailing cone system. All pressure and temperature gauges were calibrated prior to testing in the engineering integration laboratory, building 1600, Edwards Air Force Base. Instrument corrections and calibration data are shown in appendix C.

ON-AIRCRAFT LEAK CHECKS AND END-TO-END CHECKS

The trailing cone system was checked for static pressure leaks pre- and post-flight to verify system plumbing integrity. Static pressure leak checks were performed using a TTU-205 Pitot-static tester connected to the static sleeve using a special adaptor. A five minute leak check was performed at a simulated pressure altitude of 20,000 feet before and after each sortie. No significant leaks were found. Leak rates were less than 100 feet per minute and typically ranged between 40 and 60 feet per minute.

Static pressure lag checks were not performed since pacer mission test points typically consist of stable points during which any transients or lags in static pressure would be damped out.

TRAILING CONE FLYING CHARACTERISTICS

The flying characteristics of each trailing cone system length were observed during all flying qualities sorties to ensure sufficient stability existed for each system length before proceeding with tower flyby test points. Flying qualities sorties consisted of takeoff, landing, and stabilized cruise points at various altitudes and airspeeds throughout the subsonic flight envelope.

TAKEOFF AND LANDING

Observations of the trailing cone system flying qualities during takeoff and landing were important to ensure the system did not sustain damage or contact the aircraft flight control surfaces. Real-time observations and post-flight review of takeoff and landing video data were used to analyze safety of flight and trailing cone flying characteristics. Takeoff conditions and comments are discussed below and summarized in table D-1. After each sortie, the trailing cone system was examined for damage and wear. System damage is discussed in the Trailing Cone System Postflight Condition section of this report and detailed in appendix E.

Test aircraft takeoff methodology was modified twice during the test program based on observations of the trailing cone system flying qualities. The methods were modified in an attempt to minimize system damage and increase stability of the system during takeoff. Takeoff methods were modified by decreasing the rate that aircraft power was increased to allow the cone to fly on its own, on top of the engine plume, before larger power settings caused it to flail. Observations and results for each trailing cone system takeoff and landing method used are discussed below.

Takeoff Method #1 and Results

The takeoff methods for the first two sorties with the 65-foot and 50-foot systems were performed according to the procedure outlined in the test plan. After taxiing onto the end of the runway, the ground crew deployed the cone at a 45 degree angle from the tail of the

aircraft. The pilot then initiated a rolling takeoff from the runway centerline using a gradual increase in thrust from idle to military power. After brake release, the pilot used up to 70 percent rpm to begin rolling, selected idle, and then increased power in two percent rpm per second increments until the “cone flying” call was received from the ground crew indicating the trailing cone system was stable and not contacting the ground or the aircraft. After the “cone flying” call, the pilot increased power slowly and smoothly to reach military power. The runway was inspected by Airfield Management after each takeoff and landing for debris from the trailing cone system.

Takeoff Method #2 and Results

Damage to the trailing cone system during the first two sorties and the flying characteristics of the systems during the first two takeoff rolls prompted the test team to change the takeoff method. The takeoff procedure was revised in an attempt to stabilize the engine and exhaust plume to ensure the cone would achieve stable flight on takeoff roll and minimize whipping and impact of the system with the runway. The second takeoff method used was based on a takeoff procedure which was developed and tested during “*Calibration of an F-16B Pacer Aircraft – Fixed-Length Trailing Cone Calibration”* (option number 3, reference 4). For the second takeoff method, the trailing cone was deployed with the test aircraft at the hold-short line. The pilot then used 70 percent rpm to breakaway from a stop and selected idle power for the turn onto the runway centerline. The aircraft was allowed to accelerate in idle power for 1,000 feet, at which point a gradual increase in power from idle to military was performed at two percent rpm per second. Acceleration during the 1,000 feet at idle power was negligible. Military power was achieved passing the 11,000 feet remaining marker. This takeoff method did not minimize cone flailing during the takeoff roll for the 35-foot cone takeoff. In fact, cone flailing was more violent during this takeoff roll than on any previous trailing cone takeoffs. The test team determined this was due to the decrease in cone length and system weight, causing the cone to whip violently due to its proximity to engine exhaust, which was the main contributor to cone flailing. Cone instabilities were sufficiently violent to propel the cone forward and whip the pressure tubing to within 10 feet of the aircraft horizontal control surfaces. The flailing of the 35-foot cone system was not attributed to the takeoff method; longer trailing cone system lengths were more damped and stable during takeoff. The proximity of the 35-foot trailing cone system to the aircraft flight controls was unacceptable. When the 35-foot system takeoff characteristics were combined with the cruise flying qualities results described in the Cruise section of this report, the test team determined that the 35-foot system was unsuitable for flight test. **Do not use the 35-foot trailing cone system. (R1[1])**

Takeoff Method #3 and Results

For the remaining takeoffs, the trailing cone was deployed with the test aircraft at the hold short line. The aircrew increased power to 70 percent to roll onto the runway perpendicular to the runway centerline. The aircrew selected idle for the turn onto the runway

[1] Numerals preceded by an R within parentheses at the end of a sentence correspond to the recommendation numbers tabulated in the Conclusions and Recommendations section of this report.

centerline, gradually increased power to 75 percent at a rate of one percent every two seconds, and held 75 percent rpm to accelerate for the first 1,000 feet. The pilot then gradually increased power at the same rate to military power. Using this method as the aircraft began the rolling takeoff, the cone would drag behind the aircraft until the aircraft reached approximately 20 KCAS. The drag cone would then “fly” approximately one to two feet above the ground as aircraft speed increased. At approximately 40 KCAS, the cone transitioned into the engine plume which typically resulted in a five to eight foot trailing cone oscillation with the potential for the drag cone to contact the runway during the oscillation. Around 60 to 70 KCAS, the oscillation stopped and the cone stabilized on the upper portion of the engine exhaust plume and began “flying”. “Cone flying” calls were received at airspeeds between 60 and 110 KCAS. Takeoff ground roll distances averaged 5,500 feet with military power typically achieved at 140 KCAS.

Table 2 summarizes the progression of the three takeoff methods. Takeoff method #3 was successfully performed for the final six sorties without incident. **Perform fixed-length trailing cone equipped takeoffs using takeoff method #3. (R2)**

Table 2. Takeoff Method Summary and Results

Takeoff Method	Lineup Position	Power Setting For First 1,000 Feet	Rate of Power Increase	Result
1	Runway centerline	65-70% to begin rolling	2% per second	Undesirable trailing cone system flailing
2	Hold short line	Idle	2% per second	Decreased flailing, little acceleration between brake release and 1,000 feet down runway
3	Hold short line	75%	1% every 2 seconds	Acceptable flailing and acceleration rate

Landing Method

The aircrew performed a flight manual landing on all sorties. Trailing cone flying qualities during landing were uneventful. All systems, regardless of length, settled to the runway smoothly during aircraft deceleration and did not exhibit any bouncing or violent behavior. After the trailing cone system cleared the active runway, the pilot made a sharp turn towards the drag cone. The turn offset the Nylaflow® tubing to the side of the exhaust plume and reduced the chance of heat damage; the engine exhaust plume was also pointed away from ground personnel who approached the aircraft, coiled the tubing, and fastened it to the closest missile rail with cable ties. The ground crew examined the trailing cone system during recovery and notified airfield management if anything was missing (to alert the debris sweep crew).

Although it was possible to achieve safe takeoffs and landings using the methods discussed above, there was no in-flight indication if the severity of potential damage to the trailing cone system would lead to inaccuracies in the pressure data collected during the rest of the sortie until post-flight system inspection and leak checks. A retractable trailing cone system would minimize system damage by eliminating system dragging or impact with the

runway during takeoff and landing. Use of a retractable trailing cone system would also reduce the risk of releasing debris and minimize the need for a modified takeoff method. Preventing trailing cone system damage during takeoff would provide confidence that each sortie flown would result in usable and accurate trailing cone system data. Minor damage to the test article was sustained during every sortie due to dragging on takeoff. This damage limited the life of the trailing cone system and would be minimized if the system were capable of extending and retracting during flight. **Explore the option of equipping the F-16B pacer aircraft with an extendable and retractable trailing cone system. (R3)**

CRUISE

Trailing cone system flying qualities cruise points consisted of 15 and 30 second stabilized points at various Mach numbers throughout the subsonic flight envelope. Airspeeds and altitudes were chosen in a buildup fashion starting at the heart of the F-16B flight envelope and moving towards higher incompressible dynamic pressures. Doublets, level accelerations, and level decelerations were performed at intervals during cruise in order to evaluate the cone systems' flying characteristics. The test points flown (altitude, airspeed, and incompressible dynamic pressure) are identified in table D-2. During flying qualities cruise points, a chase aircraft was used to observe the trailing cone system flying qualities.

Data were collected during flying qualities sorties to enable calibration of the pacer noseboom air data system at a later date. Also, data collected during flight were used to determine if a relationship existed between trailing cone system length and trailing cone pressure measurement oscillations. The average over two second intervals of the standard deviations of trailing cone static pressure measurements was used to evaluate the pressure measurement variation of the different trailing cone systems. The data parameters collected during flight are identified in table B-1.

During the cruise portion of the flying qualities sorties, all trailing cone systems exhibited some degree of "cone rocking" and "guitar stringing". Cone rocking consisted of the drag cone partially rotating between +/- 15 to 30 degrees left and right of center at a frequency of less than one hertz as shown in figure 2.

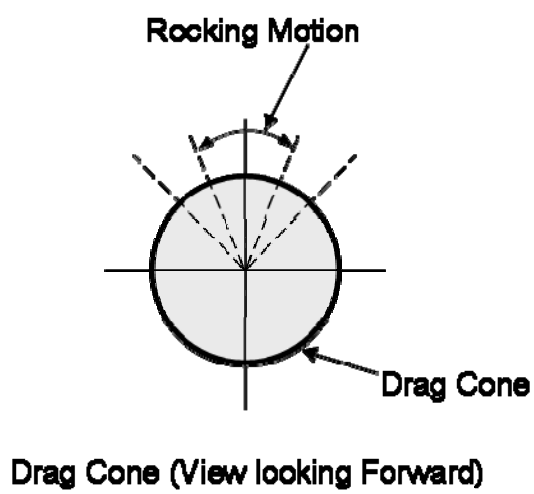

Figure 2. Drag Cone Rocking Motion

Cone rocking had the potential to result in twisting of the static pressure tube. The drag cone and static pressure tubing were connected via a coupling. The pressure tubing and drag cone coupling consisted of a bolt, nut and radial bearing through which the bolt passed through. The radial bearing design had the potential to lock-up as incompressible dynamic pressure increased the drag on the cone and in turn the load on the bolt and bearing. Locking of the coupling was one cause of the observed cone rocking. During testing of the 35-foot trailing cone system, the pressure tubing rotated as the drag cone rotated resulting in the Nylaflow® tube twisting as shown in figure 3. During testing of the 35-foot system, the pressure tube and drag cone rotated in unison; this indicated that the radial bearing coupling which joined the drag cone to the end of the pressure tubing had ceased functioning properly. As a result, the pressure tubing became twisted and three sections of the pressure tubing were permanently deformed.

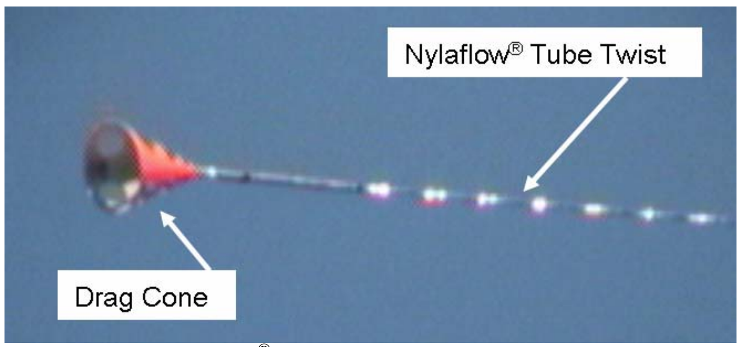

Figure 3. 35-foot System Nylaflow® Tube Twist (0.92 Mach number, 10,000 feet PA)

Replacing the radial bearing with a thrust bearing would allow the coupling to better withstand the axial load experienced during high incompressible dynamic pressures and prevent the coupling from locking up as was observed for the 35-foot trailing cone system. **Modify the design of the pressure tube and drag cone coupling to allow independent pressure tube and drag cone rotation under axial loads due to incompressible dynamic pressure. (R4)**

"Guitar stringing" was used to describe the high frequency vibration of the pressure tube of the trailing cone system since the motion resembled that of a guitar string when plucked. The nodes of pressure tube vibration were observed to occur at the static tube and the junction of the drag cone and Nylaflow® tubing, as shown in figure 4. Mild guitar stringing was defined as the Nylaflow® tubing vibrating equal to or greater than +/- six inches off center (dimension A or B equal to 12 inches or greater as seen in figure 4). Light guitar stringing was defined as the Nylaflow® tubing vibrating equal to or less than +/- three inches off center (dimension A or B = six inches or less as seen in figure 4).

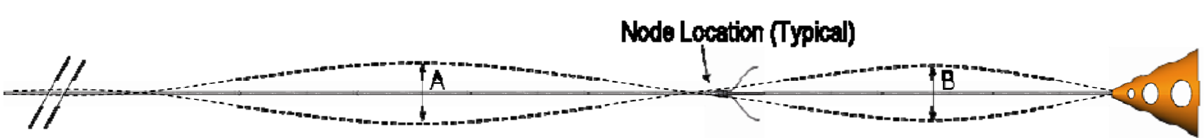

Figure 4. Guitar Stringing

35-foot Trailing Cone System Flying Qualities

The 35-foot trailing cone system experienced guitar stringing throughout the flight envelope tested. The amplitude of guitar stringing for the 35-foot system was significantly higher than other systems tested with the total amplitude at locations A and B in figure 4 being approximately 1 foot as judged by the chase crew at 30,000 feet pressure altitude (PA). For the 30,000, 20,000 and 10,000 feet PA points flown, the 35-foot system variation in pressure altitude averaged four feet (0.002105 inches of mercury, in Hg) and was a maximum of seven feet (0.003 in Hg) at 30,000 feet PA, 0.96 Mach number (see table D-2 and figure D-1).

Testing of the 35-foot trailing cone system was halted at 0.92 Mach number at 10,000 feet PA (12.5 in Hg incompressible dynamic pressure) due to structural deformation of the drag cone as seen in figure 5. At this flight condition, the drag cone deformed to an oval-shaped base while rotating slowly (approximately 0.5 revolutions/second).

Figure 5. 35-foot System Drag Cone Deformation (0.92 Mach number, 10,000 feet PA)

50-foot Trailing Cone System Flying Qualities

The 50-foot trailing cone system experienced guitar stringing and cone rocking above 0.9 Mach number at 30,000 feet PA (see table D-2 and figure D-2). During the first flying qualities test of the 50-foot system, the drag cone deformed at 10,000 feet PA and 0.85 Mach number. Deformation was accompanied by a rapid rotation of the drag cone at greater than 1 revolution/second with a center of rotation offset from the centerline of the pressure tubing by six inches as judged by the chase crew. This type of offset rotation is often referred to as "coning". This was the only occurrence of coning noted during any of the flying qualities sorties. A second flying qualities sortie was performed with the 50-foot system below the incompressible dynamic pressure at which cone deformation occurred previously. For the 30,000, 20,000 and 10,000 feet PA points flown, the variation in pressure altitude observed for the 50-foot trailing cone system was an average of three feet (0.002 in Hg) and a maximum of five feet (0.002 in Hg) at 30,000 feet PA and 0.93 Mach number (see table D-3). The variation in pressure altitude was not considered significant based on the test team's engineering judgment. Therefore, the 50-foot trailing cone system was determined to be suitable for flight test.

65-foot Trailing Cone System Flying Qualities

The 65-foot trailing cone system exhibited light guitar stringing as judged by the chase crew at 10,000 feet PA in the powered approach configuration at 0.30 Mach number and in a clean configuration at airspeeds greater than 0.92 Mach number (see table D-2 and figure D-3). Due to the limited DAS data available for the 65-foot system the only pressure altitude variation data available was at 2,500 feet PA. However, based on the observed stability of the 65-foot system at 30,000, 20,000 and 10,000 feet PA it was determined that the 65-foot system was suitable for flight test

85-foot Trailing Cone System Flying Qualities

The 85-foot system exhibited mild guitar stringing as judged by the chase crew at 10,000 feet at airspeeds greater than 0.90 Mach number (see table D-2 and figure D-4). At 2,500 feet and 0.85 Mach number, the drag cone deformed. Therefore, a second flying qualities sortie was performed with a new drag cone. During the second 85-foot flying qualities sortie guitar stringing was observed at 10,000 feet at speeds greater than 0.75 Mach number with deformation at 0.84 Mach number (see figure D-4). For the 30,000, 20,000 and 10,000 feet PA points flown, the variation in pressure altitude observed for the 85-foot trailing cone system was an average of three feet (0.004 in Hg) and a maximum of four feet (0.002 in Hg) at 30,000 feet PA and 0.75 Mach number (see table D-3). Therefore, the 85-foot system was determined to be suitable for flight test.

TRAILING CONE STATIC SOURCE ERROR CORRECTIONS

The tower flyby method was used to determine the static source error corrections (SSEC) to be applied to the pressure data recorded from each of the trailing cone systems. The trailing cone system static sleeve was assumed to be out of the influence of the aircraft so that it was sensing the freestream pressure. The SSEC curves were developed to show a non-dimensional pressure error correction coefficient as a function of equivalent airspeed:

$$\frac{\Delta P_{pc}}{P_{sic,cone}} = f(V_{e_{ic}})$$

where ΔP_{pc} was the error correction to be added to the trailing cone static pressure, $P_{sic,cone}$ was the trailing cone static pressure corrected for instrument errors, and $V_{e_{ic}}$ was the instrument-corrected equivalent airspeed calculated using the instrument-corrected static and total pressures from the test aircraft system number 2. The pressure altitude correction, ΔH_{pc} was also determined as a function of instrument-corrected equivalent airspeed using the pressure error correction coefficients. The use of instrument-corrected equivalent airspeed made the non-dimensional SSEC curves valid at all altitudes. Appendix F shows the detailed data analysis procedure for the tower flyby method.

TOWER FLYBY RESULTS

Tower flyby was the flight test method used to determine the SSEC curves for the different lengths of trailing cone systems. As discussed in the Limitations and Drag Cone Deformation Analysis sections of this report, due to structural deformation of the cone the 50-foot and 65-foot trailing cone systems were the only two systems that were used for tower flybys. The maximum airspeeds flown during tower flyby sorties were set to minimize potential cone deformation. The flybys for the 50-foot system were flown between 11 degrees angle of attack (approximately 170 KCAS) and 0.71 Mach number (approximately 450 KCAS). The 65-foot system was flown between 11 degrees angle of attack and 0.82 Mach number (approximately 525 KCAS).

The non-dimensional SSEC results, $\Delta P_{\text{pc}} / P_{sic,cone}$ are shown in figure G-1 for the 50-foot system length and figure G-2 for the 65-foot system length. The SSEC curves for the 50-foot and 65-foot systems were approximately linear between 250 and 450 KEAS. The test team collected data above 450 KEAS for only the 65-foot system, so no comparison of the two systems was made above 450 KEAS.

The pressure altitude corrections (ΔH_{pc}) were analyzed to determine which trailing cone system length produced the most consistent, minimally variant results. Pressure altitude corrections are shown in figure G-3 for the 50-foot system length, figure G-4 for the 65-foot system length, and figure G-5 for a comparison of both lengths. Four replicate test points were flown at low (11 degrees angle of attack or 170 KCAS) and medium (350 KCAS) airspeeds on each tower flyby sortie to statistically determine the minimally variant system length. Replicate test points were also flown at high airspeeds, but because the maximum airspeed flown for each length was different, no statistical comparison was made. The replicated test points were flown first during each sortie, in a randomized order to ensure independence, and then intermediate airspeeds were flown to populate the remainder of the calibration curves.

The data available for statistical analysis consisted of eight low airspeed and eight medium airspeed replicates for both the 50-foot and 65-foot systems. The data from the 65-foot system tower flybys indicated a discrepancy in ΔH_{pc} values. The test team determined that the discrepancy was caused by errant readings from the primary (Setra) and secondary (Druck) pressure sensors in the flyby tower. The first 65-foot sortie was flown in the afternoon, while all other tower flyby sorties were flown during the early morning; research into the weather conditions for the first sortie revealed that the average ambient temperature (outside the flyby tower) was 90 degrees F. The maximum calibrated operating temperatures for the Setra and Druck pressure transducers were 110 degrees F and 86 degrees F respectively. The Druck transducer was out of its advertised calibrated operating range; the Setra transducer was also likely out of its advertised calibrated range because of temperatures higher than 90 degrees F inside the tower. The higher temperatures were due to additional heating from direct sunlight on the transducers and the electrical heating of the instruments themselves. Data from this sortie were salvaged using the tertiary NovaLynx pressure altitude measurements (with maximum advertised operating temperature of 122 degrees F); this instrument was portable and not operated while in direct sunlight.

Table 3 shows the standard deviations from the 50-foot and 65-foot system pressure altitude correction measurements for the low and medium airspeed test points. The 50-foot and 65-foot system standard deviations differed by 1.1 feet at low airspeeds and were identical for the medium airspeed test points. Because of the small sample size (only eight test points per standard deviation calculation), resampling methods were used to prove that the differences in standard deviation were statistically insignificant. For each airspeed, a hypothesis was generated that the data from the two system lengths were from the same population. The 16 low airspeed (then medium airspeed) values for both systems were resampled (with replacement) 1000 times to simulate a larger overall population; then the standard deviation of each of these 1000 resampled sets was calculated. The 95 percent confidence interval for the low airspeed standard deviation had lower and upper boundaries of 4.6 and 7.6 feet and the 95 percent confidence interval for the medium airspeed standard deviation had lower and upper boundaries of 2.9 and 4.3 feet. Because the values shown in table 3 fell well within their respective 95 percent confidence intervals, the difference in standard deviation between the two trailing cone systems was deemed statistically insignificant at both low and medium airspeeds. Because the 50-foot and 65-foot systems were proven to have similar variance, the effect of trailing cone system length on pressure altitude correction variation was insignificant for those systems.

Table 3. Pressure Altitude Correction Variation at Low and Medium Airspeeds

System Length (feet)	Target Airspeed	ΔH_{pc} Standard Deviation (feet)
50	Low	7.0
65	Low	5.9
50	Medium	3.5
65	Medium	3.5

Notes: 1. Data were from tower flybys flown between 2,100-2,500 feet pressure altitude

2. Low target airspeed was the greater of 11 degrees angle of attack or 170 KCAS

3. Medium target airspeed was 350 KCAS

The relationship between trailing cone angle of attack and equivalent airspeed is shown in figure G-6 for both the 50-foot and 65-foot system lengths. The trailing cone angle of attack was measured from the angle of the drag cone relative to the horizon in the high-resolution still photographs taken of each tower flyby pass. An example of the trailing cone angle of attack and horizon reference lines is shown in figure G-7. The data indicated that trailing cone angle of attack was a function of equivalent airspeed, and further showed that the angle of attack for the 65-foot system was approximately 1.5 degrees higher than the 50-foot system at the same airspeed.

The production radar altimeter on the test aircraft was used as a pilot reference for the 150 foot tower flyby aim altitude. The radar altimeter indication in the test aircraft heads-up-display only provided the pilot 10-foot increments; however, post-flight radar altimeter data were available to the nearest foot. The aircraft was also outfitted with a G-Lite differential GPS system to provide truth position information in addition to that provided by the

theodolite measurement by the test team members in the flyby tower. The AGL information provided by these three methods is plotted for each tower flyby sortie in figures G-8 to G-11. The comparison of these sources of AGL shows that the theodolite tower reading and aircraft radar altimeter were consistently within five feet of each other while the G-Lite reading was typically offset ten feet above the other two.

TRAILING CONE SYSTEM POSTFLIGHT CONDITION

At the conclusion of each test sortie, the conditions of the trailing cone system were inspected. A detailed summary of trailing cone system damages is listed in appendix E. Conditions of the Nylaflow® tubing, skids, drag cone, and Kevlar® sleeve were documented. Regions of wear observed on trailing cone systems after every sortie are labeled in figure 2.

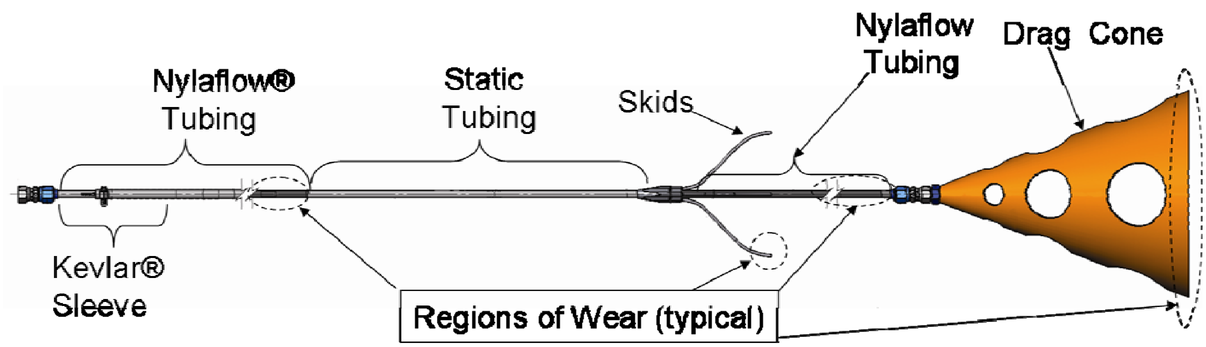

Figure 6. Regions of Typical Wear of Trailing Cone System

Skids

The skids of each system exhibited wear on the last one to two inches of the skid. Wear varied from mild surface abrasion to one skid of the 85-foot system being worn down to three-quarters of its original diameter. With the exception of the 35-foot system, all skids remained intact and prevented any wear or damage to the static tube portion of the system including the static ports. One skid was lost from the 35-foot system. The skid was known to be present prior to takeoff and was observed by the chase crew to be missing after completion of the 10,000 foot PA flying qualities test point. The loss of one of the four skids was caused by failure of the safety wire which enabled the pin holding the skid in place to be liberated thus releasing the skid (see figure E-1). Possible causes of the safety wire failure were violent oscillation on takeoff or twisting of the Nylaflow® tubing during flight.

Nylaflow® Tubing

The skids had the negative effect of inducing wear on the Nylaflow® tubing. The location of the skids caused the weight of the static tube to be focused on the skids and the section of Nylaflow® tubing just forward of the rigid static tube. As a result, all systems exhibited wear on the Nylaflow® tubing from zero to four inches immediately forward of the static tube. Wear consisted of abrasion marks limited to the surface of the Nylaflow® tubing due to

contact with the runway on takeoff and landing. Adding a protective layer of tape or other material to prevent damage to the Nylaflow® tubing forward of the static tube may disrupt the airflow seen by the static tube.

The trailing cone system exhibited a pronounced whipping and impact with the runway when the cone entered and exited the aircraft exhaust plume during the takeoff rolls for the first two sorties (65-foot and 50-foot lengths). Inspection of the trailing cone system after the first two flights revealed that the Nylaflow® tubing was severed immediately forward of the drag cone. Also, the rigid tube which the drag cone connected to was bent during the second sortie (see figures E-2 and E-3). Damage to the Nylaflow® tubing and rigid drag cone connection tube was determined to be the result of the system whipping and impacting the runway on takeoff. Based on observations during takeoff and post-flight damage assessment, the trailing cone system was reinforced for subsequent flights with a layer of shrink wrap, plastic spiral wrap, and an outer layer of silicone tape covering 18 inches forward from the end of the Nylaflow® tubing. No further breaks in the Nylaflow® tubing were observed on subsequent flights. **Reinforce the Nylaflow® tubing for the first 18 inches forward of the drag cone to prevent damage during takeoff and landing. (R5)**

<u>Static Tube</u>

No wear or damage was observed to any portion of the static tube on any of the trailing cone systems except for the 35-foot system. The static tubes were examined post-flight to determine if the static tube had been bent during each sortie. A go/no-go fixture was used to determine the straightness of each tube. The fixture was able to measure if the static tube was bent more than 0.040 inches along its length. The static tubes of each trailing cone system were within 0.040 inches in straightness except for the 35-foot system. During the only flight of the 35-foot system, the static tube was damaged. As seen in figure E-4, the static tube was bent more than 0.040 inches along the length of the tube.

<u>Drag Cone Wear</u>

Damage was noted on the aft edge of each drag cone for every system. During the takeoff roll (regardless of takeoff method) the drag cone was dragged for between 10 (35-foot system) and 1000 feet (85-foot system) depending on system length. During landing, the drag cone of the system dragged on the runway after nose touchdown until the system was clear of the active runway. As a result, the aft edge of the trailing cone was worn during each flight. The most severe wear was observed on the 65-foot and 85-foot trailing cone systems. The wear on the 65-foot system drag cone was the result of three sorties and had begun to wear through the aft edge of the cone. The wear of the drag cone on the 85-foot system was the result of a single sortie and most likely due to the excessive distance it was dragged during takeoff and landing (see figure E-5). The longer trailing cone systems required higher airspeeds before liftoff and lowered back to the ground at higher airspeeds on landing. This resulted in longer length systems being dragged for longer distances on the runway causing additional damage to the drag cones.

Kevlar® Sleeve

The 30 foot section of Kevlar® sleeve did not experience damage during any of the sorties regardless of system length. The maximum temperature experienced by the Kevlar® sleeve was monitored during each sortie though the use of Omegalabel® temperature monitor strips placed at 10, 20 and 30 feet on the Kevlar® sleeve from the end of the vertical tail. The maximum temperature observed on any sortie was 250 degrees F measured 30 feet from the vertical tail; this occurred on the second of three 65-foot trailing cone system sorties. No damage due to heating of the tubing was observed forward of the Kevlar® sleeve. The maximum operational temperature of Nylaflow® tubing was 150 degrees F, 100 degrees less than the maximum temperature the trailing cone system experienced. The maximum operating temperature of the Kevlar® sleeve was 600 degrees F. Therefore, failure to use the protective Kevlar® sleeve could result in Nylaflow® tubing damage as a result of exposure to temperatures above its maximum operating temperature. **Use a protective Kevlar® sleeve on at least the first thirty feet of Nylaflow of the trailing cone systems. (R6)**

Drag Cone Deformation Analysis

One drag cone attached to the 35-foot and 50-foot systems and two drag cones attached to the 85-foot trailing cone system deformed during flying qualities testing. Drag cone deformation occurred at incompressible dynamic pressures ranging from 10.1 to 13.8 in Hg. To determine the cause of the drag cone deformation, each of the drag cones used during testing was weighed and the thickness of the cone measured and presented in table E-1. A relationship between drag cone weight, incompressible dynamic pressure and structural deformation was observed. As seen in figure E-6, a linear relationship between cone weight and incompressible dynamic pressure at the point of cone deformation was determined. A variation in cone thickness was also observed as seen in table E-1. The drag cone was a composite of fiberglass fiber strand mat and vinyl ester resin. The variation in cone weight and thickness, which was a function of fiber and resin content of the cone, determined the overall structural integrity of the cone and ultimately the maximum incompressible dynamic pressure the cone could withstand without deformation. **Establish a structural rigidity requirement for the drag cone as necessary to achieve desired mission requirements. (R7)** Common industry practices vary drag cone size (diameter, length) to change the overall drag force experienced by the drag cone. The influence of cone size and drag force were not investigated during testing.

Overall, the 50-foot trailing cone system attained satisfactory flying qualities, equivalent static source error correction variance to the 65-foot system, and sustained less system damage on takeoff and landing than the other lengths. However, due to the limitations specified in this report it was impossible to draw a firm conclusion on which trailing cone system was the best. **Continue flight test to establish a clearly optimal trailing cone system. (R8)**

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CONCLUSIONS AND RECOMMENDATIONS

The overall test objective was to evaluate four different trailing cone system lengths and determine which length provided the best combination of trailing cone flying characteristics and static pressure data quality. The selected trailing cone system would exhibit minimally variant static source error corrections and operationally acceptable pressure altitude oscillations. The following recommendations are listed in prioritized order.

Trailing cone systems of 35-foot, 50-foot, 65-foot and 85-foot lengths were evaluated in flight for airworthiness and stability. The flying characteristics of each trailing cone system were observed during takeoff, landing and cruise portions of all flying qualities sorties. Three different takeoff procedures were used during testing. The most desirable takeoff flying characteristics were observed using takeoff procedure #3. This procedure resulted in six successful takeoffs with minimal damage to the trailing cone system.

Perform fixed-length trailing cone equipped takeoffs using takeoff method #3. (R2, page 8)

The behavior of the 35-foot system during takeoff was unstable and sufficiently violent to propel the cone forward and whip the pressure tubing within 10 feet of the test aircraft's horizontal control surfaces. The proximity of the 35-foot trailing cone system to aircraft flight controls was unacceptable.

Do not use the 35-foot trailing cone system. (R1, page 7)

Landings were performed per the flight manual with no undesirable flying qualities for any system tested.

Guitar stringing and cone rocking were observed for each system tested during the flying qualities sorties. Although all trailing cone systems exhibited light guitar stringing, the observed altitude oscillations of the 50-foot, 65-foot and 85-foot trailing cone systems at 30,000, 20,000 and 10,000 feet were suitable for the systems to be used as a calibration truth source.

The 50-foot and 65-foot systems were tested using the tower flyby method to determine the static source error corrections and pressure altitude corrections for the trailing cone systems. The data were analyzed to determine whether trailing cone system length was a factor in variability of the correction values. Because the 50-foot and 65-foot systems were proven to have similar variance, the effect of trailing cone system length on pressure altitude correction variation was insignificant for those systems.

The 50-foot trailing cone system attained satisfactory flying qualities, equivalent static source error correction variance to the 65-foot system, and sustained less damage on takeoff and landing than the other lengths. However, due to the limitations specified in this report it was impossible to draw a firm conclusion on which trailing cone system was the best.

Continue flight test to establish a clearly optimal trailing cone system. (R8, page 17)

During testing of the 35-foot trailing cone system, the pressure tubing twisted and plastic deformation occurred due to drag cone rotation translated upstream to the pressure tubing. The current design of the pressure tubing and drag cone coupling did not allow the tubing and drag cone to rotate independently as drag increased on the cone. Replacing the current radial bearing with a thrust bearing for all trailing cone system lengths would prevent the tubing and drag cone coupling from locking, and would result in simultaneous rotation of the drag cone and static tubing.

Modify the design of the pressure tube and drag cone coupling to allow independent pressure tube and drag cone rotation under axial loads due to incompressible dynamic pressure. (R4, page 10)

Drag cone damage was noted on the aft edge of all drag cones during post-flight inspections due to the trailing cone system being dragged behind the aircraft during takeoff and landing. The damage to the drag cone was greater for longer length systems (85-foot and 65-foot).

One drag cone used for the 35-foot and 50-foot systems and two drag cones used for the 85-foot trailing cone system deformed during flying qualities testing. Drag cone deformation was observed to occur during testing at incompressible dynamic pressures ranging from 10.1 to 13.8 in Hg. Post-flight analysis showed a relationship between drag cone weight, incompressible dynamic pressure, and structural deformation. The cone structural integrity was a function of cone weight and thickness and impacted the maximum incompressible dynamic pressure the cone could withstand without deformation.

Establish a structural rigidity requirement for the drag cone as necessary to achieve desired mission requirements. (R7, page 17)

The condition of the skids, static tube, Nylaflow® tubing, drag cone and maximum temperature experienced by the Kevlar® sleeve was documented after each sortie. The skids of each system exhibited wear on the last one to two inches of the skid; the maximum wear observed was one skid worn down to three-quarters of its original thickness due to dragging on the runway. All skids remained intact with the exception of the 35-foot system. The skids prevented wear to the static tube portion of the system. However, use of the skids did result in surface abrasion and wear to the Nylaflow® tubing just forward of the static pressure tube due to angle the skids caused the tubing to contact the runway. Wear to the Nylaflow® tubing was minor and attempts to protect the Nylaflow® tubing forward of the static tube with silicone tape or shrink wrap may disrupt the airflow sensed by the static tube ports.

Damage to the Nylaflow® tubing and rigid drag cone connection tube was observed to occur on the first two sorties as a result of the system whipping and impacting the runway on takeoff. As a result, the trailing cone system was reinforced for subsequent flights with a layer of shrink wrap, plastic spiral wrap, and an outer layer of silicone tape covering the first

18 inches forward from the Nylaflow® tubing and drag cone connection. No further breaks in the tubing were observed on subsequent flights.

Reinforce the Nylaflow® tubing for the first 18 inches forward of the drag cone to prevent damage during takeoff and landing. (R5, page 16)

The Kevlar® sleeve did not experience damage during any of the sorties regardless of system length. The maximum temperature experienced by the Kevlar® sleeve was 250 degrees F at the end of the sleeve (30 feet from the vertical tail). The maximum operational temperature of Nylaflow® tubing was 150 degrees F. Failure to use the protective Kevlar® sleeve could result in damage to the Nylaflow® tubing.

Use a protective Kevlar® sleeve on at least the first thirty feet of Nylaflow of the trailing cone systems. (R6, page 17)

Although it was possible to achieve safe takeoffs and landings using the flight test procedures, damage to the system was unavoidable due to system dragging on takeoff and landing. No method was available to determine if the damage during takeoff influenced the quality of the data collected during each sortie. A retractable trailing cone system would reduce the potential for released debris, avoid system damage by preventing the trailing cone system from dragging or impacting the runway or test aircraft during takeoff and landing, and thus increase the likelihood of useable data being collected during the remainder of the sortie.

Explore the option of equipping the F-16B pacer aircraft with an extendable and retractable trailing cone system. (R3, page 9)

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APPENDIX A – TEST LOG

System Length (ft)	Date (D-M-Y)	Sortie Number	Mission	Crew		Pressure Tube		Drag Cone		Cone Number	Pressure Transmitter S/N	Notes
				Front Cockpit	Rear Cockpit	P/N	S/N	P/N	S/N			
65	05-Mar-07	1	FQ	Iyer	Gilbreath	100107	035307	4152-01	034306	2	97609	1,2
65	16-Mar-07	4	FQ / TFB	Iyer	Gilbreath	100107	035307	4152-01	034306	2	97609	-
65	19-Mar-07	5	TFB	Reinhardt	Hoenle	100107	035307	4152-01	034306	2	97609	-
50	07-Mar-07	2	FQ	Reinhardt	Welser	4152-03	041953	4152-03	041953	1	97609	2
50	23-Mar-07	8	FQ / TFB	Iyer	Starr	4152-03	041953	4152-02	041599	2	97609	-
50	26-Mar-07	9	TFB	Reinhardt	Chua	4152-03	041953	4152-02	041599	2	97609	-
35	13-Mar-07	3	FQ	Reinhardt	Chua	4152-02	041599	4152-02	041599	1	97609	-
85	20-Mar-07	6	FQ	Reinhardt	Welser	4152-01	035306	4152-01	035306	1	97609	-
85	21-Mar-07	7	TFB	Reinhardt	Jutte	4152-01	035306	4152-03	041953	2	97609	-

Flying Qualities (FQ)
Tower Flyby (TFB)
Part Number (P/N)
Serial Number (S/N)

Notes: 1. PC/104 data acquisition system nonfunctional during first 65-foot sortie
2. Tubing was broken forward of the drag cone and repaired prior to subsequent sorties.

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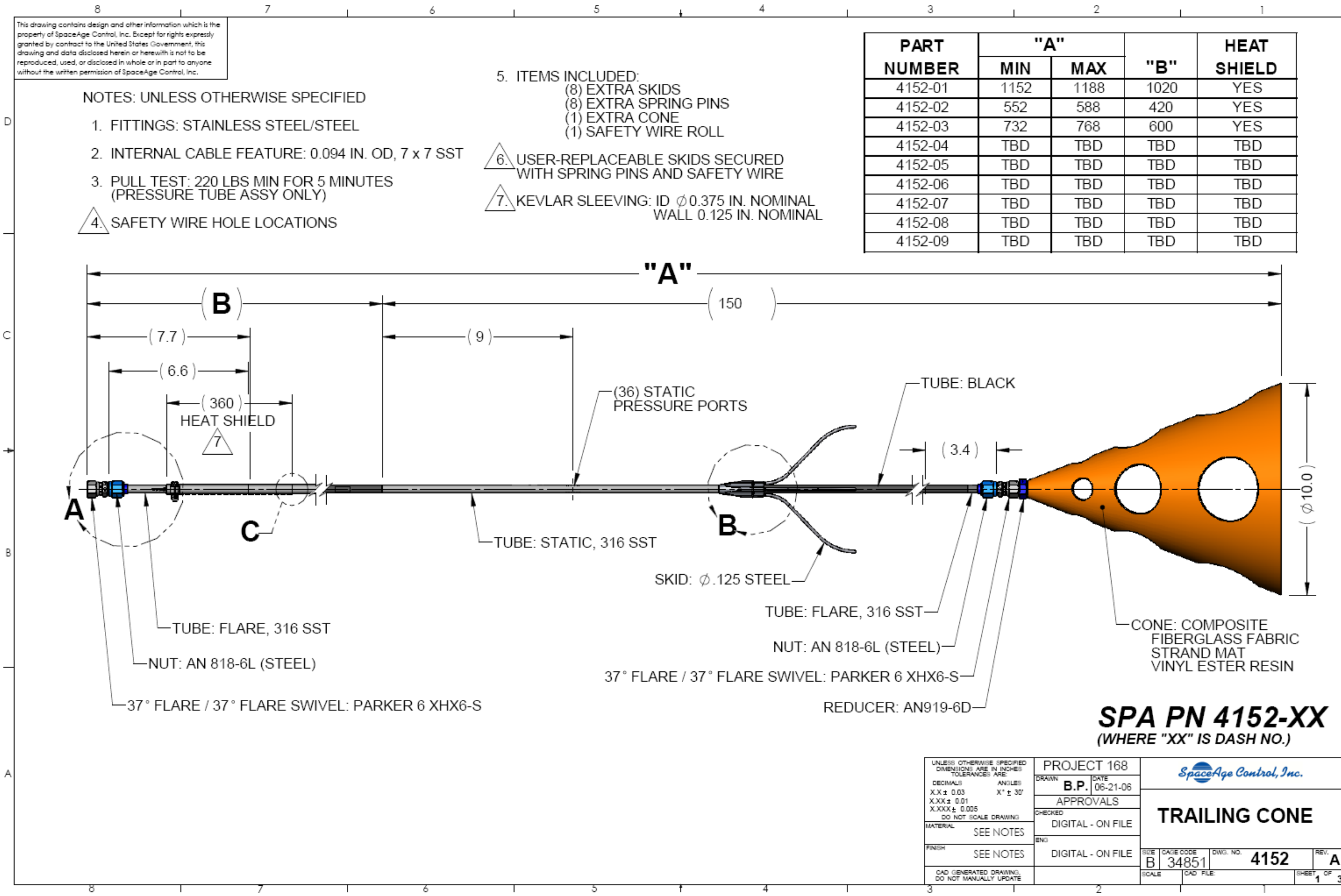
APPENDIX B – DETAILED TEST ITEM DESCRIPTION

Trailing Cone System

A fixed-length trailing cone system was installed on the aircraft for the dual purposes of providing high-accuracy pressure altitude data for use in calibrating the pacer noseboom system and for use in directly calibrating the air data systems on other test aircraft. The system consisted of an anchor fixture, a high-accuracy pressure transducer, Nylaflow® pressure tubing reinforced with a steel cable, a heat-resistant Kevlar® fire sleeve, a stainless steel static pressure sensing sleeve with skids, and a drag cone. Detailed technical drawings of the trailing cone system are shown in figure B-1, figure B-2, and figure B-3.

Values for the nominal trailing cone system (referred to as the 50-foot tubing length), are specified below; the remaining tubing length (35, 65, and 85-foot) parameters were obtained by adding or subtracting the difference from the 50-foot length. The trailing cone system was attached to the aft tip of the vertical stabilizer in the location of the radar threat warning system, which was removed to accommodate the trailing cone system anchor fixture. The anchor fixture was installed on the rear-facing bulkhead. The anchor fixture was painted flight test orange with black stripes. A Paroscientific 0 to 15 psia pressure transducer with an accuracy of 0.0015 psia was installed inside the anchor fixture. This level of accuracy was equivalent to approximately ±11 feet at 40,000 feet pressure altitude. The SpaceAge Control (Palmdale, California) trailing cone had a length of approximately 52 feet (37, 67, and 87 feet) between the anchor point and the static sleeve. The overall length of the assembly was approximately 65 feet (50, 80, and 100 feet). The trailing cone system had a length of approximately 62 feet (47, 77, and 97 feet) between the anchor point and the static sleeve and an overall length of approximately 75 feet (60, 90, and 110 feet). The part numbers for the trailing cone systems used are reflected in the Test Log in appendix A. All trailing cone models featured stainless steel, replaceable skids that provided protection to the static sleeve. The first 30 feet of the Nylaflow® tubing was covered with 0.125-inch thick Kevlar® fire sleeve to protect against heat damage. The fire sleeve was fastened to the tubing with a hose clamp near the anchor point. The other end of the fire sleeve was sealed with epoxy to prevent fraying. This end of the fire sleeve was not fastened to the tube. The pressure tubing underneath the fire sleeve could be inspected by loosening the hose clamp and sliding the fire sleeve along the tubing. Data from the pressure transducer was time-stamped and recorded on the PCMCIA card in the PC/104.

The 50-foot trailing cone length was chosen based on historical data and comparison with other fighter-type aircraft with trailing cone installations. The 60 and 85-foot trailing cone lengths were chosen to further distance the static ports from the influence of the aircraft. The 35-foot trailing cone length was chosen based on the hypothesis that a shorter length may eliminate exhaust plume interactions.



PART NUMBER	"A" MIN	"A" MAX	"B"	HEAT SHIELD
4152-01	1152	1188	1020	YES
4152-02	552	588	420	YES
4152-03	732	768	600	YES
4152-04	TBD	TBD	TBD	TBD
4152-05	TBD	TBD	TBD	TBD
4152-06	TBD	TBD	TBD	TBD
4152-07	TBD	TBD	TBD	TBD
4152-08	TBD	TBD	TBD	TBD
4152-09	TBD	TBD	TBD	TBD

Figure B-1. Technical Drawing of Trailing Cone System

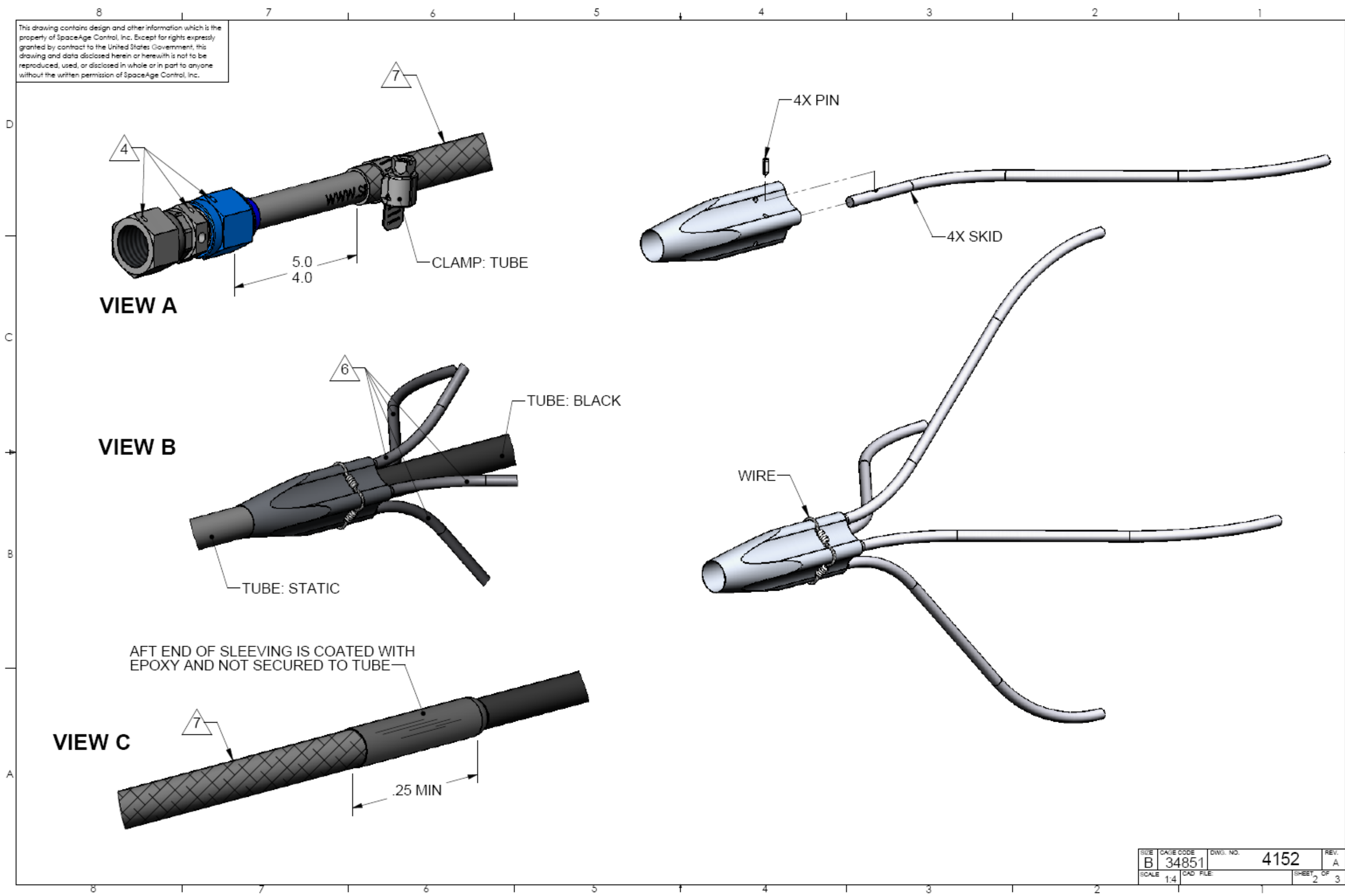


Figure B-2. Trailing Cone System Anchor Fixture, Kevlar® Sleeve, and Skids

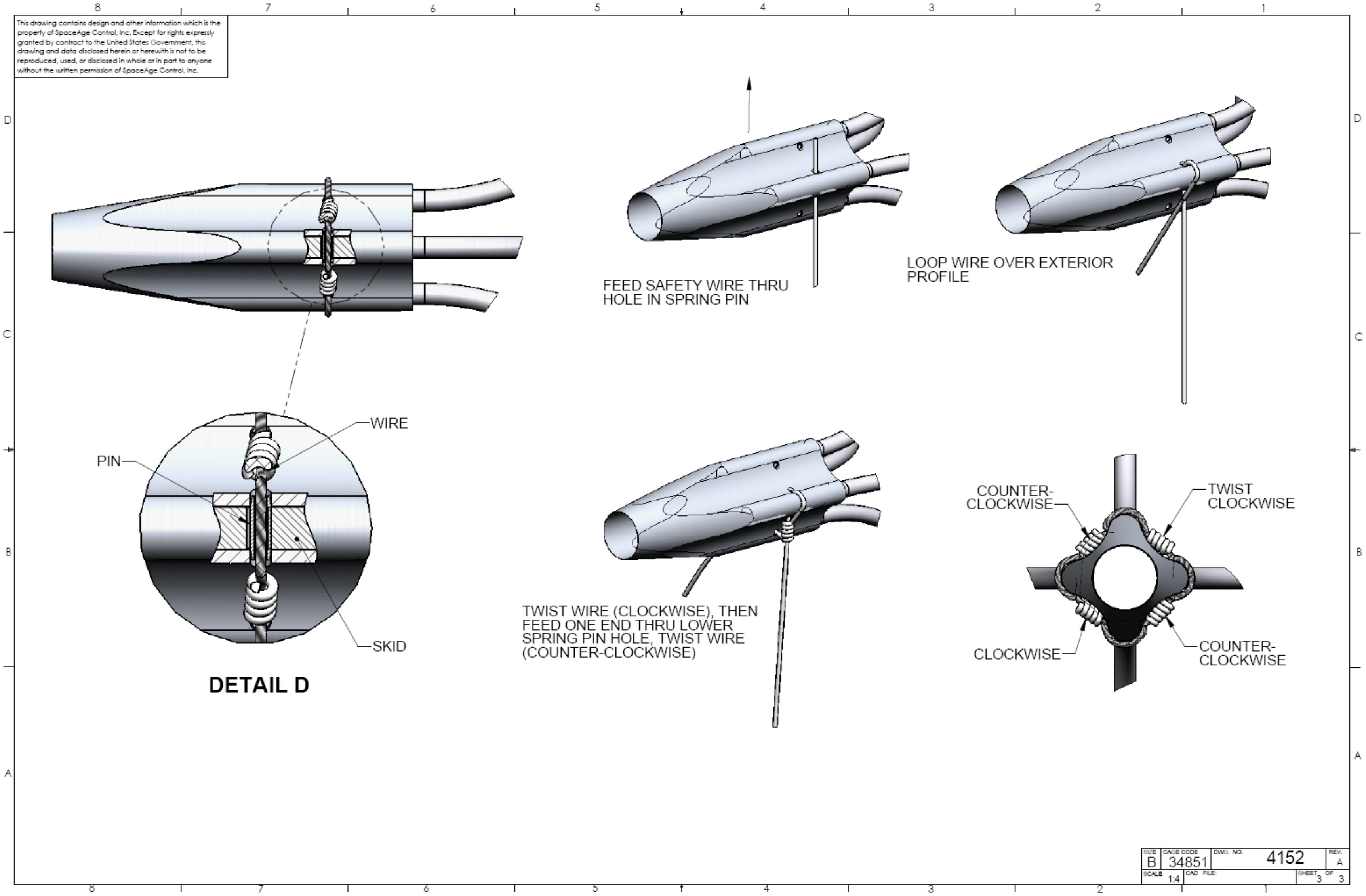


Figure B-3. Trailing Cone System Skid Safety Wire Design

Pacer Air Data Equipment

A schematic of the production F-16B noseboom air data system is illustrated in figure B-4. This figure was been modified to depict where the pacer Dual Sonix® digital pressure encoders were connected (labeled "pacer ADS connections"). The production air data system included a Pitot-static probe mounted on the nose that provided a dual source of static and total pressures. A second, production five-hole air data probe was mounted on the forward right side of the fuselage and provided another source of static and total pressures for the production central air data computer (CADC). These pressures were used by the CADC to estimate aircraft angle of attack and angle of sideslip. Two additional cone-type production angle of attack transducers were installed, one on either side of the forward fuselage. A flight test total air temperature probe was mounted on the underside of the left forebody strake and provided the pacer air data system with a total air temperature measurement. The production total air temperature probe was mounted on the right side of the fuselage.

The special instrumentation on the F-16B test aircraft used the production F-16B noseboom-mounted air data probe to collect data for both total and static pressure systems. The air data probe incorporated a single Pitot port and two separate static ports comprising two semi-independent Pitot-static systems numbered "one" and "two". Each of the Pitot-static systems was connected to calibrated Dual Sonix® pressure transducers. The sensitive transducers provided input signals to the Advanced Airborne Test Instrumentation System (AATIS) which output engineering unit data to the pacer cockpit displays, a PC/104 flashcard memory, and a MARS-II digital recorder.

The test aircraft cockpits displayed calibrated data from the noseboom (data corrected for both instrument and position errors) in a digital format. Both the Pitot-static system source (system 1 or 2) presented on the display screens and the pacer system data recording rate were selectable from the rear cockpit. The PC/104 was the primary pacer data recording system and recorded calibrated data from both Pitot-static systems for post-flight analysis. The MARS-II tape recorder was used to record the AATIS pulse code modulation (PCM) data, voice, time code, and 1553 avionics multiplexer bus data for post-flight analysis. The AATIS PCM stream included instrument-corrected static and total pressure from both Pitot-static systems as well as total air temperature. Data from the MIL-STD-1553 bus were also recorded to the MARS-II. Major AATIS components included the following:

1) MARS II digital recorder: recorded all AATIS instrumentation parameters, to include pacer system control unit (SCU)-3 outputs and 1553 avionics MUX bus data.

2) PS-7000 Dual Sonix® digital pressure encoders: converted total and static pneumatic pressures to digital format for AATIS.

3) PC/104 computer: configured and programmed for serial input, digital input, digital output, and PCMCIA flashcard recording capability. This computer was a commercial-off-the-shelf IBM computer for industrial embedded applications.

4) GPS time code generator: provided automatic synchronization with GPS satellites to generate the IRIG-B Time Code.

The F-16B pacer aircraft used a pair of Dual Sonix® digital pressure encoders, part number PS7000, to measure total and static pressures for the two air data systems (number 1 and 2). Both air data systems used the production noseboom and the Pitot port located at the tip of the boom. Pacer air data system 1 fed the primary system in the front cockpit (FCP). Air data system 2 fed the secondary system in the rear cockpit (RCP). The static ports were located 15.25 inches forward of the nose of the aircraft. Dual Sonix® serial number 8 was installed in system 1 and serial number 14 was installed in system 2. The noseboom Pitot-static lines contained drain connections for moisture and contaminate removal. The Dual Sonix® transducers were located approximately 190 inches aft of the noseboom on the left side of the fuselage.

A non-deiced Rosemount total temperature probe, model number 102E, serial number 498, was installed on the left side of the fuselage on panel number 3107. A production, deiced total temperature probe was installed on the right side of the fuselage.

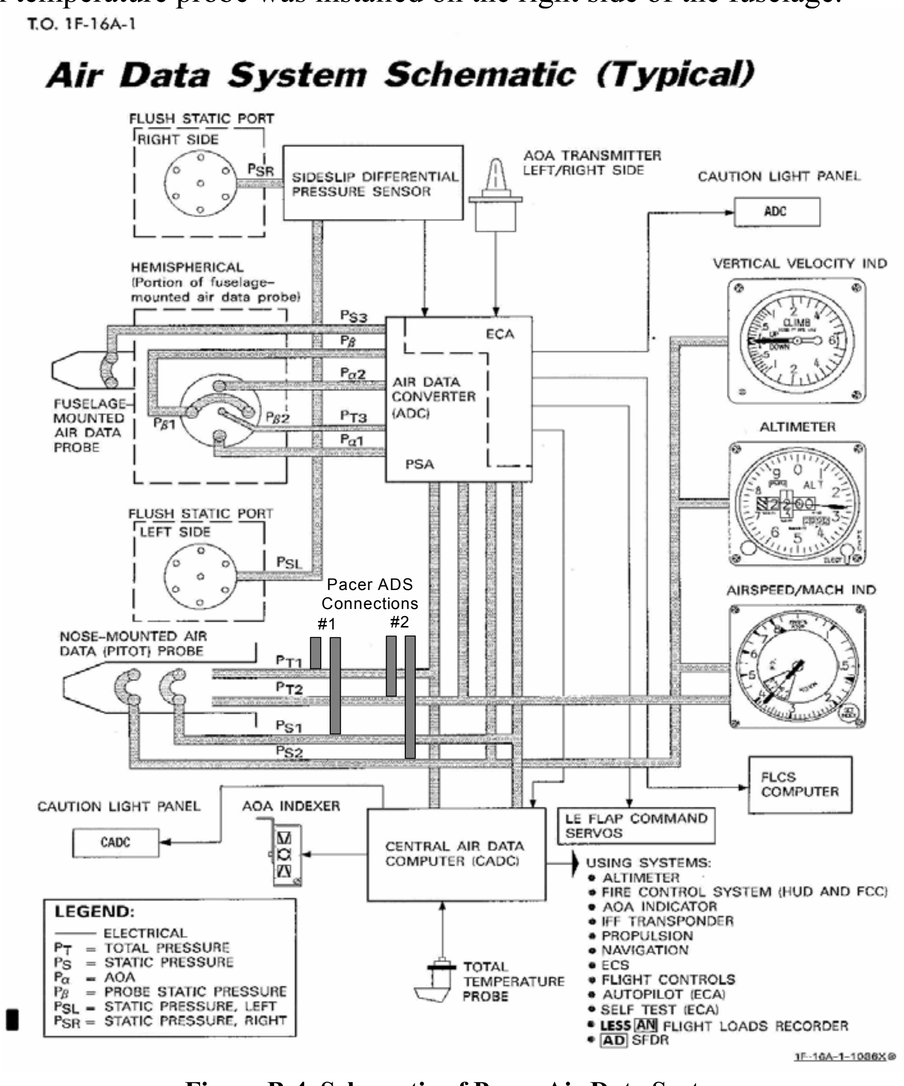


Figure B-4. Schematic of Pacer Air Data System

Pacer Parameter List

The data parameters used from the MARS-II recorder are listed in table B-1. The processed outputs are also listed in the table.

G-Lite Parameter Lists

The parameters available from the G-Lite are listed in table B-2.

Special Instrumentation

The AATIS consisted of a system control unit (SCU-3), a virtual processor (VP), a multiple data bus monitor unit (MDBM), and a small pulse code modulation unit (SPCM). The SCU-3 contained a virtual processor to convert raw pressure and temperature data into airspeed, altitude, Mach number and temperature information. These calculated engineering unit (EU) parameters were then displayed on cockpit digital display units. Raw and EU data were also recorded on a PC/104 flashcard and recorded on a MARS II data recorder. The aircraft was equipped with a GPS time code generator and video time inserter. The production video recorder had been replaced with a Hi8mm video deck. A general test support fleet C-Band beacon had been added for range support. A pacer special instrumentation block diagram is shown in figure B-5.

Control Panels and Displays

a. Instrumentation Master Power Panel	- FCP Right Console (figure B-6)
b. Video Control Panel	- FCP Left Console
c. 2 Digital Readouts	- FCP Left Instrument Panel
d. Pacer Control Panel	- RCP Left Console (figure B-7)
e. Recorder Control Panel	- RCP Left Console (figure B-8)
f. Time Code Display (TCD)	- RCP Left Console
g. 3 Digital Readouts	- RCP Left Auxiliary Console (figure B-9)

Switching instrumentation master power panel switch to ON energized relays in the power junction box (PJB) to power up ATIS power supply in the ammo bay pallet and other pacer system components.

MARS II Tape Recorder

The MARS-II recorder was located on the ammo pallet, accessed through the gunbay access panel. The MARS-II was a standard airborne test recorder that utilized a 20 gigabyte tape. The recorder was powered up for loading and unloading tape.

AATIS

The SPCM was located in the ammo bay on the top shelf. It accepted analog inputs from the two Dual Sonix® PS7000 Pitot-static digital pressure encoders and one total air

temperature probe. The MDBM was located on the ammo pallet on the top shelf. The SCU-3 was located on the ammo pallet on the bottom shelf and contained the virtual processor. The AATIS power supply was located on the ammo pallet on the bottom shelf.

Timing System

A TrueTime 705-205 GPS IRIG-B receiver provided time, frequency, and position information as derived from signals transmitted by NAVSTAR GPS and was usable on a world wide basis. IRIG time was obtained within 3 minutes when the GPS antenna had an unobstructed view to the sky. The receiver was located on the ammo pallet on the top shelf.

PC/104

The pacer had a PC/104 computer system to input RS-232 data from the SCU-3 VP and the trailing cone pressure transducer and record those data onto a PCMCIA ATA Type II flashcard in standard PC text file format.

The PC/104 system consisted of a small 115 volt AC to 28 volt DC power supply, a PC/104 computer, and a preflight panel. The PC/104 had one PCMCIA flash card memory slot. It accepted up to a 240 MB memory card. The preflight panel had an OFF/RECORD switch for memory removal with pacer power on. It also had a run indication to show when a print command was received by the PC/104. The print output was recorded in standard text file format on the PCMCIA flash card. Two dated files were recorded on each mission: one with a ".F16" extension which was comma and quotation delimited, and one with a ".RAW" extension. These files were able to be read by any PC with a PCMCIA reader, and read with any text editor. The files contained one line of data per record.

G-Lite

A G-Lite differential GPS receiver/recorder was installed in the aircraft. The G-Lite position data was used as an alternate position truth source for the tower flyby method and cruise calibration test points. The G-Lite used the production GPS antenna.

The G-Lite differential GPS receiver/recorder was installed in the gun breach area. A two line display, configuration one G-Lite without shock mounts was installed. The body coordinates of the GPS antenna on the test aircraft were: fuselage-station 255.49 inches, body-line 0.00 inches and water-line 121.33 inches.

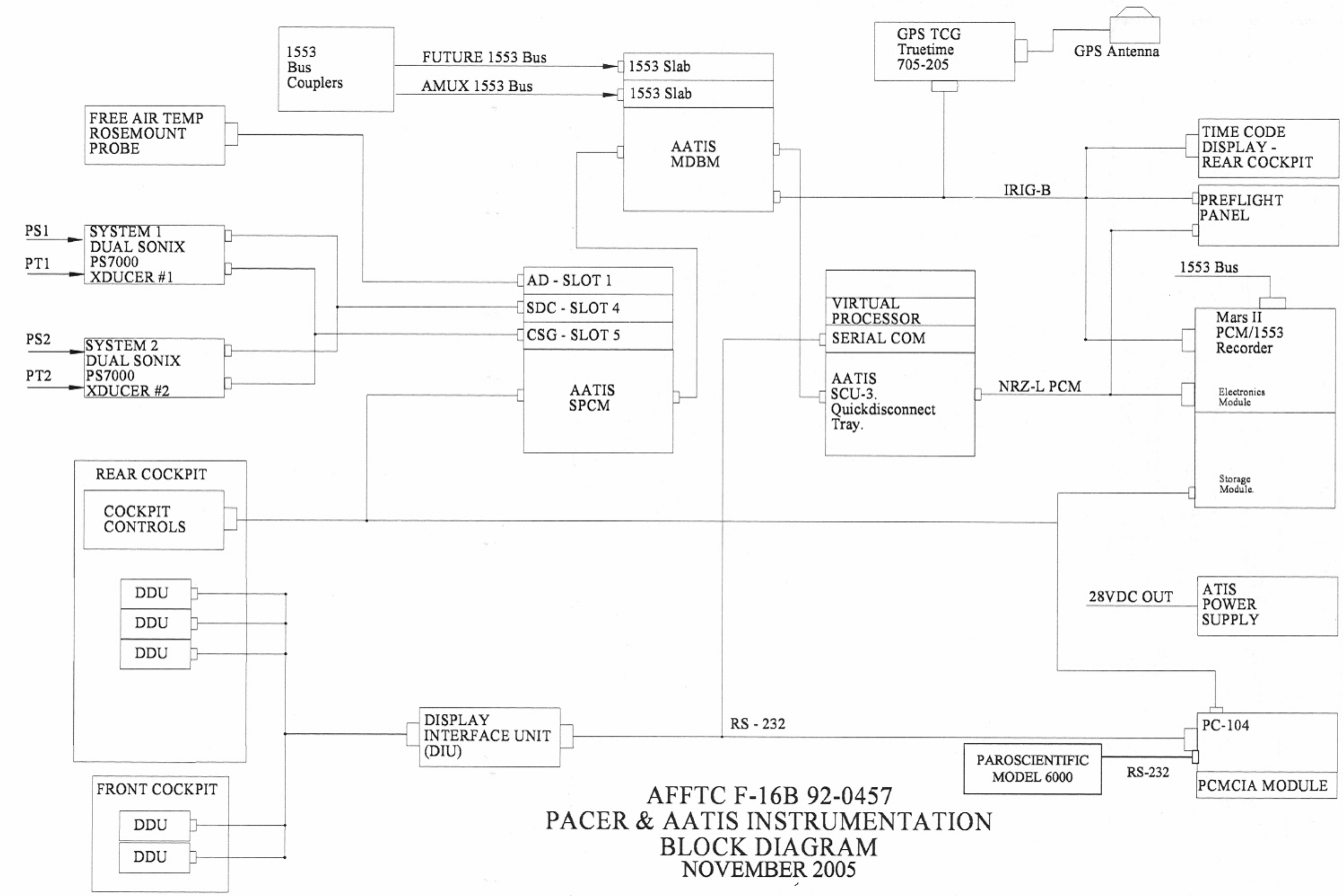


Figure B-5. Pacer Special Instrumentation Schematic

Figure B-6. Pacer Instrumentation Master Power Panel (Front Cockpit)

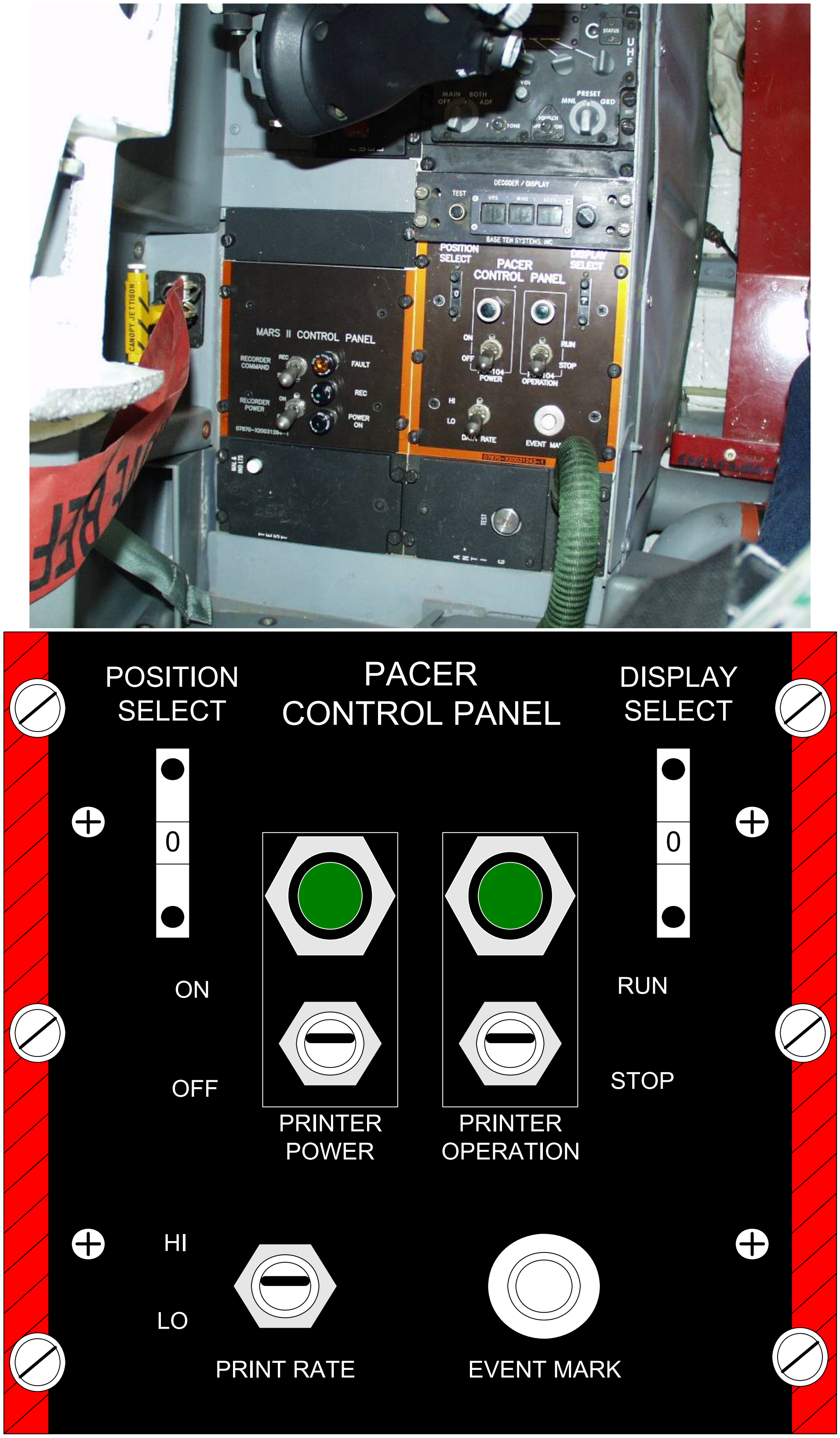


Figure B-7. Pacer Control Panel (Rear Cockpit)

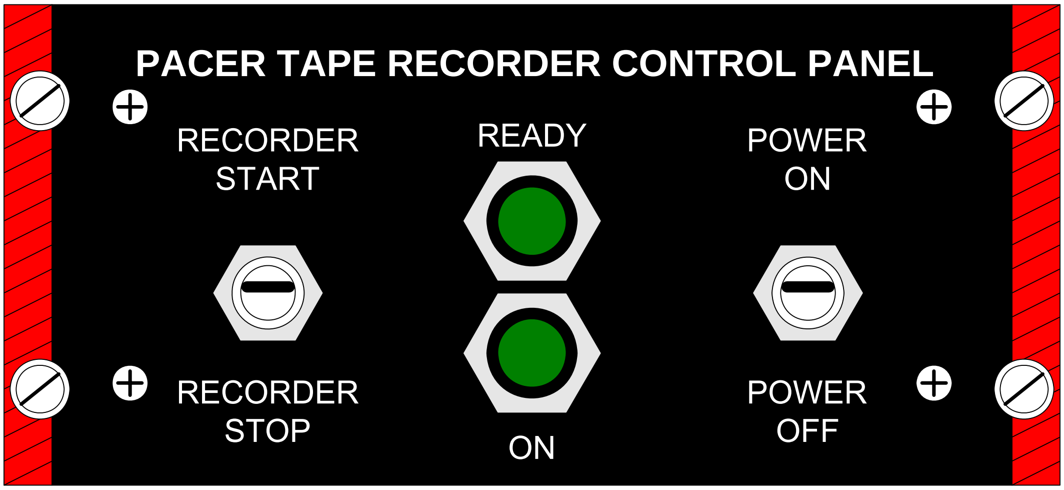


Figure B-8. Pacer Tape Recorder Control Panel (Rear Cockpit)

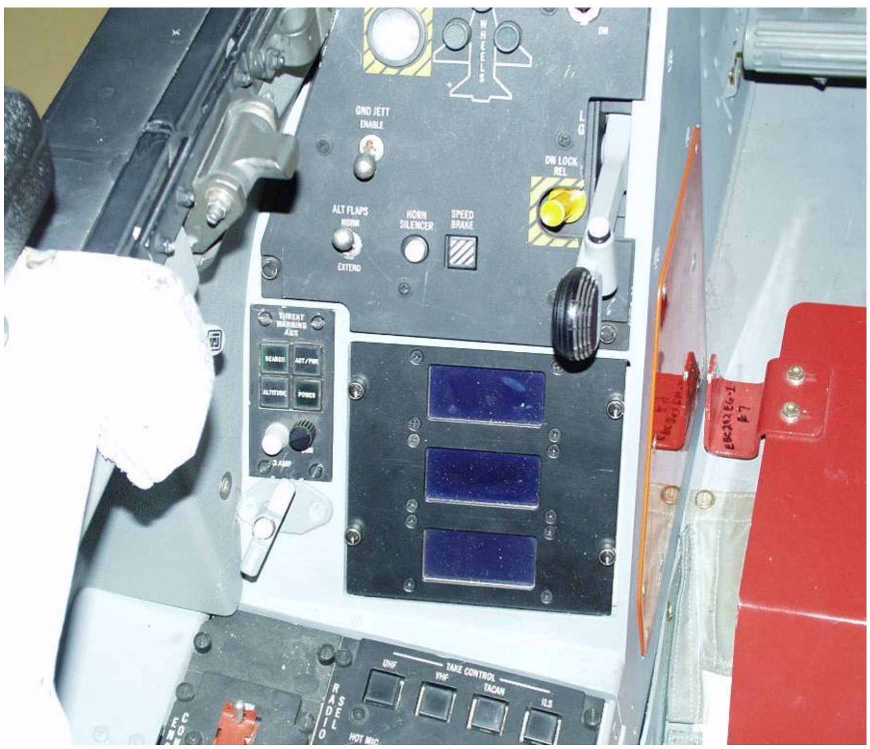


Figure B-9. Air Data Displays (Rear Cockpit)

Table B-1. Legend of Data Parameter Names

Parameter Name	Units	Description
A/C AoA (MARS-II)	Deg	Aircraft angle of attack
Cone AoA (photo)	Deg	Trailing cone angle of attack based on still photos
Delta H	Feet	Difference of pressure altitude of aircraft and Zero Grid Line
Delta H_ic_cone	Inch_HG	Instrument corrections for trailing cone static pressure
Delta H_pc_1	Feet	Altitude position correction for Dual Sonix® static pressure transducer 1, based on theodolite grid reading
Delta H_pc_1_add	Feet	Additional altitude position correction required for Dual Sonix® static pressure transducer 1
Delta H_pc_1_orig	Feet	Reverse calculation of original altitude position correction applied for Dual Sonix® static pressure transducer 1
Delta H_pc_2	Feet	Altitude position correction for Dual Sonix® static pressure transducer 2, based on theodolite grid reading
Delta H_pc_2_add	Feet	Additional altitude position correction required for Dual Sonix® static pressure transducer 2
Delta H_pc_2_orig	Feet	Reverse calculation of original altitude position correction applied for Dual Sonix® static pressure transducer 2
Delta H_pc_cone	Feet	Altitude position correction for cone, based on theodolite grid reading
Delta H_tower	Feet	Tapeline altitude of aircraft above Zero Grid Line based on theodolite data
Delta M_pc_1_add	Mach	Additional Mach position correction required for pacer system 1
Delta M_pc_1_cone	Mach	Mach position correction for pacer system 1 based on trailing cone static pressure
Delta M_pc_1_orig	Mach	Reverse calculation of original Mach position correction applied for pacer system 1
Delta M_pc_1_tower	Mach	Mach position correction for pacer system 1 based on ambient pressure at zero grid line
Delta M_pc_2_add	Mach	Additional Mach position correction required for pacer system 1
Delta M_pc_2_cone	Mach	Mach position correction for pacer system 2 based on trailing cone static pressure
Delta M_pc_2_orig	Mach	Reverse calculation of original Mach position correction applied for pacer system 2
Delta M_pc_2_tower	Mach	Mach position correction for pacer system 2 based on ambient pressure at zero grid line
Delta P_p/P_q_cic_2	ND	Position error coefficient for pacer system 2
Delta P_p/P_s_1	ND	Static port position error for Dual Sonix® static pressure transducer 1
Delta P_p/P_s_2	ND	Static port position error for Dual Sonix® static pressure transducer 2
Delta P_p/P_s_cone	ND	Static port position error for trailing cone
Delta P_p/q_cic_1	ND	Position error coefficient for pacer system 1
Delta V_pc_1_add	Knots	Additional airspeed position correction required for pacer system 1
Delta V_pc_1_cone	Knots	Additional airspeed position correction for pacer system 1 based on trailing cone static pressure
Delta V_pc_1_orig	Knots	Reverse calculation of original airspeed position correction applied for pacer system 1
Delta V_pc_1_tower	Knots	Airspeed position correction for pacer system 1 based on ambient pressure at zero grid line
Delta V_pc_2_add	Knots	Additional airspeed position correction required for pacer system 2
Delta V_pc_2_cone	Knots	Additional airspeed position correction for pacer system 1 based on trailing cone static pressure
Delta V_pc_2_orig	Knots	Reverse calculation of original airspeed position correction applied for pacer system 2
Delta V_pc_2_tower	Knots	Airspeed position correction for pacer system 2 based on ambient pressure at zero grid line

Table B-1. Legend of Data Parameter Names (Continued)

Parameter Name	Units	Description
GR	ND	Theodolite grid reading
H_AGL_Ralt	Feet	Geometric altitude of aircraft above ground level, based on radar altimeter data
H_AGL_cone	Feet	Geometric altitude of aircraft above ground level on trailing cone data
H_AGL_Glite	Feet	Geometric altitude of aircraft above ground level based on G-Lite data
H_AGL_tower	Feet	Geometric altitude of aircraft above ground level on based on theodolite data
H_AGL_video	Feet	Tapeline altitude of aircraft above Zero Grid Line based on video recording
H_c	Feet	True pressure altitude of aircraft, corrected for ambient temperature
H_ic_1	Lbs/Feet^2	Instrument corrected pressure altitude based on pacer system 1
H_ic_2	Lbs/Feet^2	Instrument corrected pressure altitude based on pacer system 2
H_ic_cone	Lbs/Feet^2	Instrument corrected Cone pressure altitude
H_pc_1	Feet	Aircraft calibrated pressure altitude from pacer system 1
H_pc_2	Feet	Aircraft calibrated pressure altitude from pacer system 2
H_ZGL	Feet	Pressure altitude at Zero Grid Line, based on pressure altitude-time model applied
M_c_1	Mach	Mach for pacer system 1 based on ambient pressure at zero grid line
M_c_2	Mach	Mach for pacer system 2 based on ambient pressure at zero grid line
M_cone_1	Mach	Mach for pacer system 1 based on trailing cone static pressure
M_cone_2	Mach	Mach for pacer system 2 based on trailing cone static pressure
M_ic_1	Mach	Instrument corrected Mach for pacer system 1
M_ic_2	Mach	Instrument corrected Mach for pacer system 2
M_pc_1	Mach	Aircraft Mach number from pacer system 1
M_pc_2	Mach	Aircraft Mach number from pacer system 2
M_pc_avg	Mach	Average aircraft Mach number for pacer system 1 and 2
P_a	Lbs/Feet^2	Ambient pressure corresponding to aircraft's true pressure altitude
P_ic_cone	Inch_HG	Instrument corrected trailing cone static pressure
P_s_1	Inch_HG Lbs/Feet^2	Aircraft instrument corrected static pressure from pacer system 1
P_s_2	Inch_HG Lbs/Feet^2	Aircraft instrument corrected static pressure from pacer system 2
P_s_cone	Inch_HG Lbs/Feet^2	Trailing cone static pressure
P_t_1	Inch_HG Lbs/Feet^2	Aircraft instrument corrected total pressure from pacer system 1
P_t_2	Inch_HG Lbs/Feet^2	Aircraft instrument corrected total pressure from pacer system 2
q_c_1	Lbs/Feet^2	Compressible dynamic pressure for pacer system 1 based on ambient pressure at zero grid line
q_c_2	Lbs/Feet^2	Compressible dynamic pressure for pacer system 2 based on ambient pressure at zero grid line
q_cic_1	Lbs/Feet^2	Instrument corrected compressible dynamic pressure for Dual Sonix® static pressure transducer 1
q_cic_2	Lbs/Feet^2	Instrument corrected compressible dynamic pressure for Dual Sonix® static pressure transducer 2
q_cic_cone_1	Lbs/Feet^2	Instrument corrected Cone compressible dynamic pressure based on Dual Sonix® static pressure transducer 1
q_cic_cone_2	Lbs/Feet^2	Instrument corrected Cone compressible dynamic pressure based on Dual Sonix® static pressure transducer 2
T_ic	Kelvin	Aircraft indicated temperature
T_SD	Kelvin	Standard day temp based on pressure altitude at Zero Grid Line

Table B-1. Legend of Data Parameter Names (Concluded)

Parameter Name	Units	Description
T_ZGL	Kelvin	Ambient temperature at Zero Grid Line, based on temperature-time model applied
V_1	Knots	Instrument corrected airspeed for pacer system 1 based on ambient pressure at zero grid line
V_2	Knots	Instrument corrected airspeed for pacer system 2 based on ambient pressure at zero grid line
V_cone_1	Knots	Instrument corrected airspeed for pacer system 1 based on trailing cone static pressure
V_cone_2	Knots	Instrument corrected airspeed for pacer system 2 based on trailing cone static pressure
V_e_ic_1	Knots	Aircraft instrument corrected equivalent airspeed for pacer system 1
V_e_ic_2	Knots	Aircraft instrument corrected equivalent airspeed for pacer system 2
V_ic_1	Knots	Instrument corrected airspeed based on Dual Sonix® static pressure transducer 1
V_ic_2	Knots	Instrument corrected airspeed based on Dual Sonix® static pressure transducer 2
V_pc_1	Knots	Aircraft calibrated airspeed from pacer system 1
V_pc_2	Knots	Aircraft calibrated airspeed from pacer system 2
V_pc_avg	Knots	Average aircraft calibrated airspeed for pacer system 1 and 2
Video_GR	ND	Theodolite grid reading based on video recording

Table B-2. G-Lite Parameter List

Number	Name	Units	Description
1	HMS	HMS	Time of Day (Hours, Minutes, Seconds)
2	ELAPS	Sec	Elapsed Time in Seconds from Zero Time
GEODETIC (WGS-84)			
107	LAT84	Deg	Latitude
108	LONG84	Deg	Longitude (+ West)
109	HGT84	Feet	Altitude
123	ITHD	Deg	INU True Heading in Degrees (+ Clockwise from North)
124	IPITCH	Deg	INU Pitch Angle (+ Counter Clockwise)
125	IROLL	Deg	INU Roll Angle (+ Counter Clockwise)

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APPENDIX C – CALIBRATION DATA

Table C-1. Instrument Corrections for the Paroscientific Pressure Transmitter Model 6001-15A, Part Number 1601-002, Serial Number 97609, 23 February 2007

Test Point #	Reference Static Pressure (in Hg)	Measured Static Pressure (in Hg) Going Up	Measured Static Pressure (in Hg) Going Down	Averaged Measured Static Pressure (in Hg)	Average Static Pressure Correction (Correction = Reference - Measured) (in Hg)
1	0.1000	0.10177	0.10155	0.10166	-0.0016
2	3.0000	3.00128	3.00126	3.00127	-0.0012
3	6.0000	6.00144	6.00136	6.00140	-0.0014
4	9.0000	9.00164	9.00156	9.00160	-0.0016
5	12.0000	12.00161	12.00154	12.00157	-0.0015
6	15.0000	15.00141	15.00137	15.00139	-0.0013
7	18.0000	18.00119	18.00125	18.00122	-0.0012
8	21.0000	21.00104	21.00105	21.00104	-0.0010
9	24.0000	24.00101	24.00092	24.00096	-0.0009
10	27.0000	27.00092	27.00099	27.00095	-0.0009
11	30.0000	30.00128	30.00115	30.00121	-0.0012

Note
1. A Ruska® air data test set model number 7252i was used to generate the reference pressures and had an accuracy of ±0.005 percent of reading.
2. The pressure correction to be added was equal to the Ruska® reference pressure minus the measured static pressure.
3. The calibration date was 23 February 2007
4. “Up” and “Down” refer to the progression of reference pressures during the test.

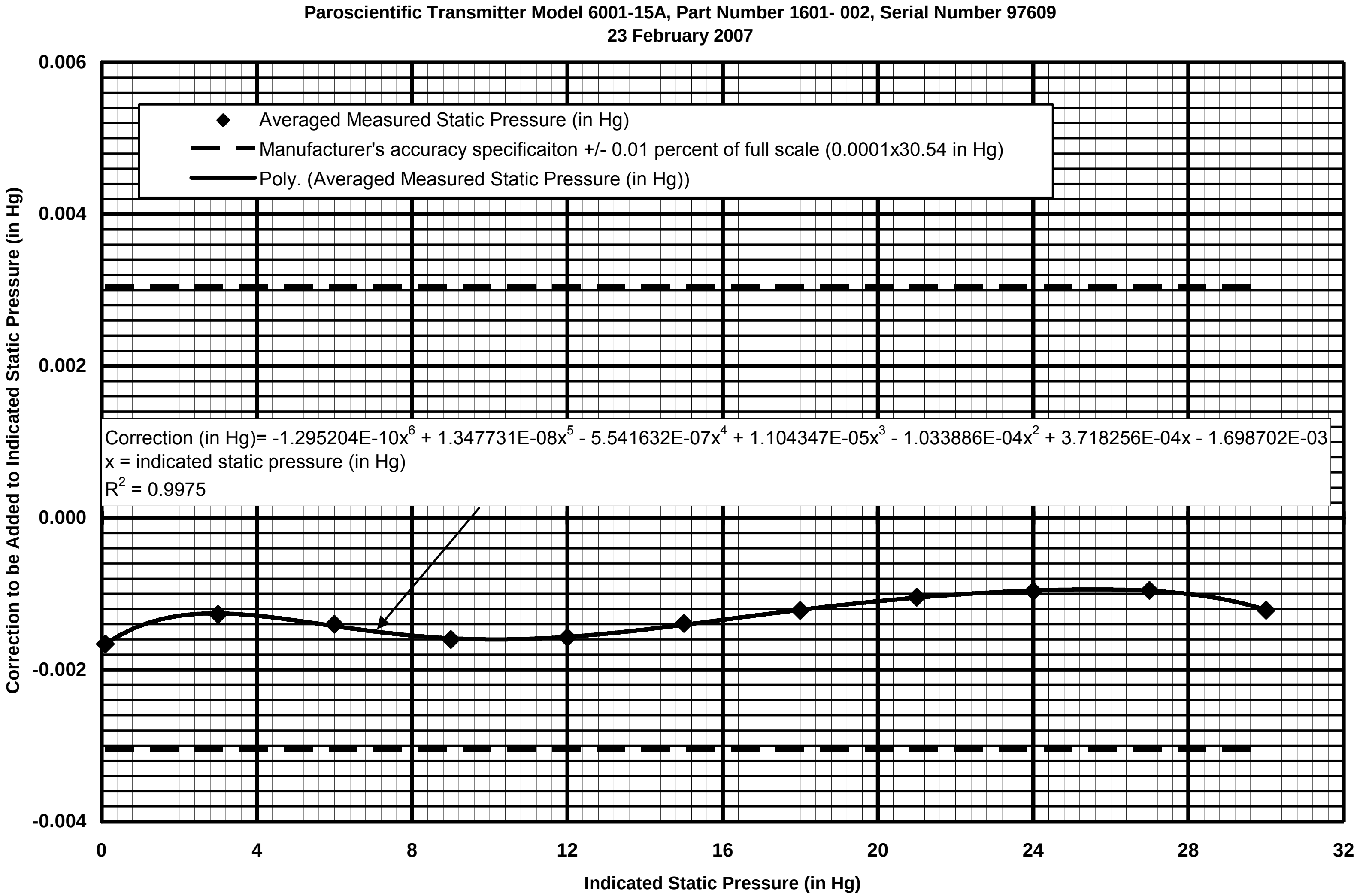

Figure C-1. Trailing Cone Pressure Transducer Instrument Corrections

APPENDIX D – FLYING QUALITIES DATA

Table D-1. Takeoff Summary

Sortie Number	System Length (ft) (Note 1)	Reinforced Tubing (Note 2)	Takeoff Method	Cone Flying % rpm	Cone Flying Airspeed (knots)	Speed or Distance for Military Power	Takeoff Distance (1000 ft)	Comments	Observations
1	**65**	no	1	79	<50	145 KCAS	5	Early "Cone Flying" call at 63 knots and 81% rpm. Extended ground roll, lift off at 175 knots	Higher than planned acceleration rate, cone stable at approximately 3000 feet from start of takeoff roll
2	**50**	no	1	-	-	3,000 feet	5	"Cone Flying" call by ground observer not heard by test	Cone did not stabilize until liftoff speed
3	**35**	yes	2	-	-	3,000 feet	5.5	No Cone Flying call made due to violent cone flailing	Significant Cone Flailing until Mil power applied. Cone objectionably close to flight controls
4	**65**	yes	3	85	65	145 KCAS	5	Sink transient experienced as gear was raised	Minor flailing
5	**65**	yes	3	80	65	5,000 feet	5.5	After turn onto runway, 70% rpm held for 500', then gradual increased at 1% rpm every 3 seconds	Minor flailing
6	**85**	yes	3	83	115	140 KCAS	6.5	Headwind: 18 knots, Crosswind: 18 knots	Stable cone throughout takeoff
7	**85**	yes	3	80	90	140 KCAS	7		Stable cone throughout takeoff
8	**50**	yes	3	81	<50	4,000 feet	5.5		Stable cone throughout takeoff
9	**50**	yes	3	80	65	145 KCAS	5.5		Stable cone throughout takeoff

Notes: 1. System length defined as the distance between transducer mounted in the aircraft vertical tail and static sleeve of drag cone system.
2. Reinforced tubing had a layer of shrink wrap, plastic spiral wrap, and an outer layer of silicone tape covering 18 inches forward from the end of the Nylaflow® tubing.
3. Takeoff Methods: 1. From runway centerline 2% rpm per second to military power
2. Rolling from hold short line. Once on runway centerline, idle power for 1,000 feet, then 2% rpm per second to military power
3. From hold short line. Once on runway centerline, 75% rpm for 1,000 feet, then 1% rpm per 2 seconds to military power

Table D-2. Trailing Cone System Flying Qualities Observations

System Length (ft)	Sortie Number	Pressure Tube P/N	Pressure Tube S/N	Drag Cone P/N	Drag Cone S/N	Pressure Altitude (ft)	Mach Number	Observations / Instability
65	**1**	**100107**	**35307**	**4152-01**	**034306**	10,000	0.92	light guitar stringing
							0.93	light guitar stringing
							0.30	small movement with power adjustment
50	**2**	**4152-03**	**41953**	**4152-03**	**041953**	30,000	0.75	light guitar stringing
							0.80	light guitar stringing
							0.85	light guitar stringing
							0.90	cone rocking
							0.95	cone rocking
						20,000	0.65	mild guitar stringing
							0.70	mild guitar stringing
							0.75	mild guitar stringing
							0.80	mild guitar stringing
							0.85	mild guitar stringing
							0.90	mild guitar stringing
							0.91	mild guitar stringing
							0.92	mild guitar stringing
							0.93	mild guitar stringing
							0.94	mild guitar stringing
							0.95	mild guitar stringing
						10,000	0.75	mild guitar stringing
							0.80	drag cone deformation
85	**6**	**4152-01**	**35306**	**4152-01**	**035306**	10,000	0.90	mild guitar stringing
							0.92	mild guitar stringing
							0.93	mild guitar stringing
						2,500	0.85	drag cone deformation
	7	**4152-01**	**35306**	**4152-03**	**041953**	10,000	0.75	mild guitar stringing
							0.80	mild guitar stringing
							0.84	drag cone deformation

P/N: Part Number
S/N: Serial Number
Instability Definitions:

Mild Guitar Stringing: Nylaflow® tubing vibrating equal to or grater than +/- 6 inches off center
Light Guitar Stringing: Nylaflow® tubing vibrating equal to or less than +/- 3 inches off center
Cone Rocking: Drag cone partially rotating between +/- 15 to 30 degrees left and right of center at a frequency of less than one hertz.

Table D-2. Trailing Cone System Flying Qualities Observations (Concluded)

System Length (ft)	Sortie Number	Pressure Tube		Drag Cone		Pressure Altitude (ft)	Mach Number	Observations / Instability
		P/N	S/N	P/N	S/N			
35	**3**	**4152-02**	**41599**	**4152-02**	**041599**	30,000	0.65	mild guitar stringing (approx 1 foot)
							0.70	mild guitar stringing (approx 1 foot)
							0.75	mild guitar stringing (approx 1 foot)
							0.80	mild guitar stringing (approx 1 foot)
							0.85	mild guitar stringing (approx 1 foot)
							0.90	mild guitar stringing (approx 1 foot)
							0.91	mild guitar stringing (approx 1 foot)
							0.92	mild guitar stringing (approx 1 foot)
							0.93	mild guitar stringing (approx 1 foot)
						20,000	0.50	mild guitar stringing
							0.55	mild guitar stringing
							0.60	mild guitar stringing
							0.65	mild guitar stringing
							0.70	mild guitar stringing
							0.75	mild guitar stringing
							0.80	mild guitar stringing
							0.85	mild guitar stringing
							0.90	mild coning (1 foot)
							0.91	mild coning (1 foot)
							0.92	mild coning (1 foot)
							0.93	mild coning (1 foot)
						10,000	0.85	mild guitar stringing
							0.90	mild guitar stringing
							0.91	mild guitar stringing
							0.92	mild guitar stringing
							0.93	drag cone deformation
							0.84	drag cone deformation

Table D-3. Flying Qualities Pressure Measurement Variation Summary

System Length (ft)	Pressure Altitude (ft)	Average Standard Deviation (ft PA)	Average Standard Deviation (in Hg)	Maximum Standard Deviation (ft PA)	Maximum Standard Deviation (in Hg)	Mach Number
35	**30,000**	5.3	0.0022	**7.3**	0.0029	**0.96**
	20,000	3.6	0.0021	4.6	0.0026	0.93
	10,000	2.5	0.0020	3.0	0.0024	0.92
Average		**3.8**	**0.0021**			
50	**30,000**	3.7	0.0015	**5.1**	0.0021	**0.93**
	20,000	2.6	0.0015	3.5	0.0020	0.95
	10,000	2.1	0.0016	2.6	0.0021	0.80
Average		**3.4**	**0.0019**			
85	**30,000**	1.7	0.0007	1.8	0.0007	0.65
	20,000	3.0	0.0018	4.1	0.0024	0.75
	10,000	2.8	0.0022	**3.8**	0.0030	**0.76**
Average		**7.5**	**0.0047**			

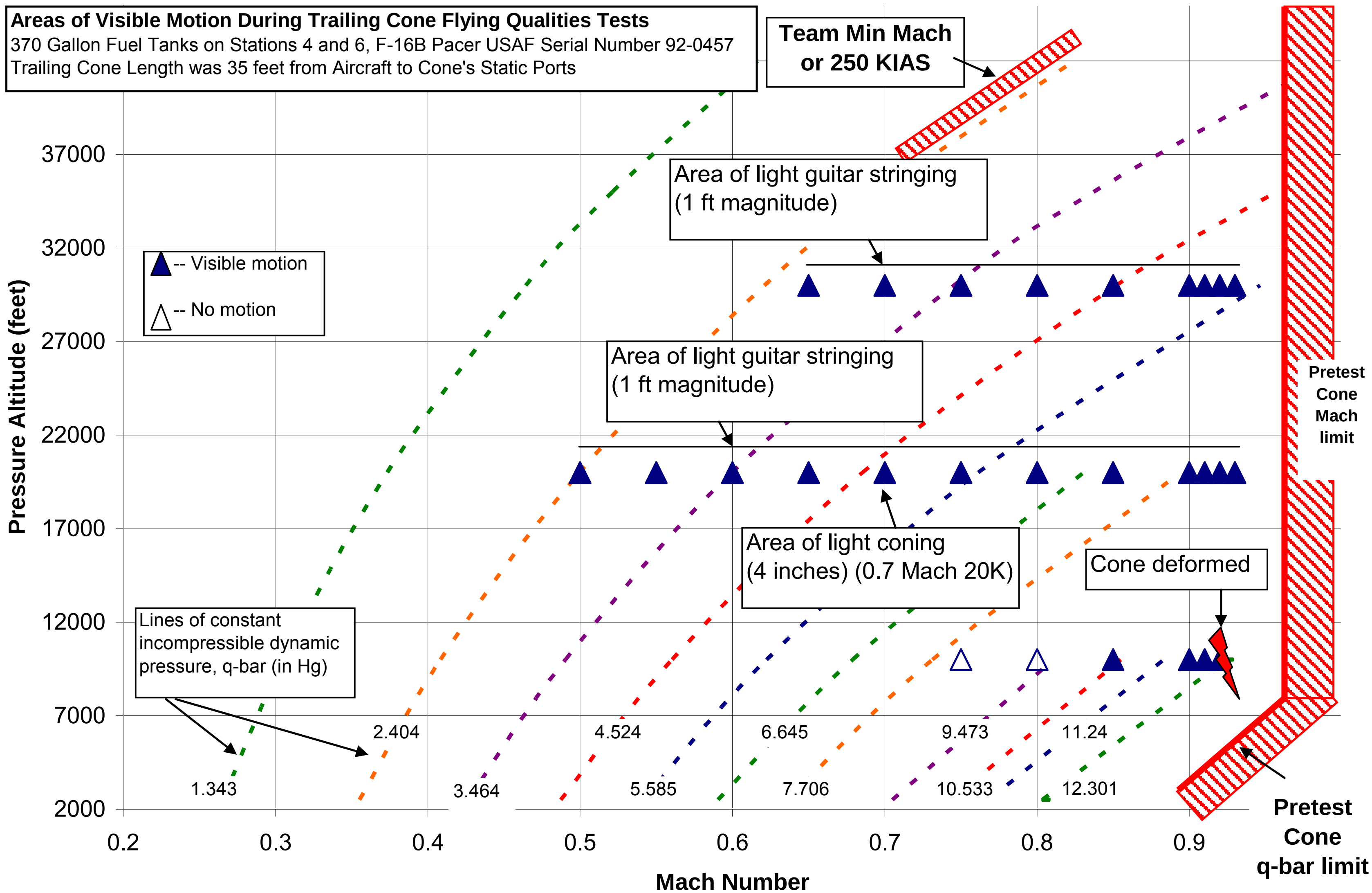

Figure D-1. Areas of Visible Motion for the 35-foot Trailing Cone System

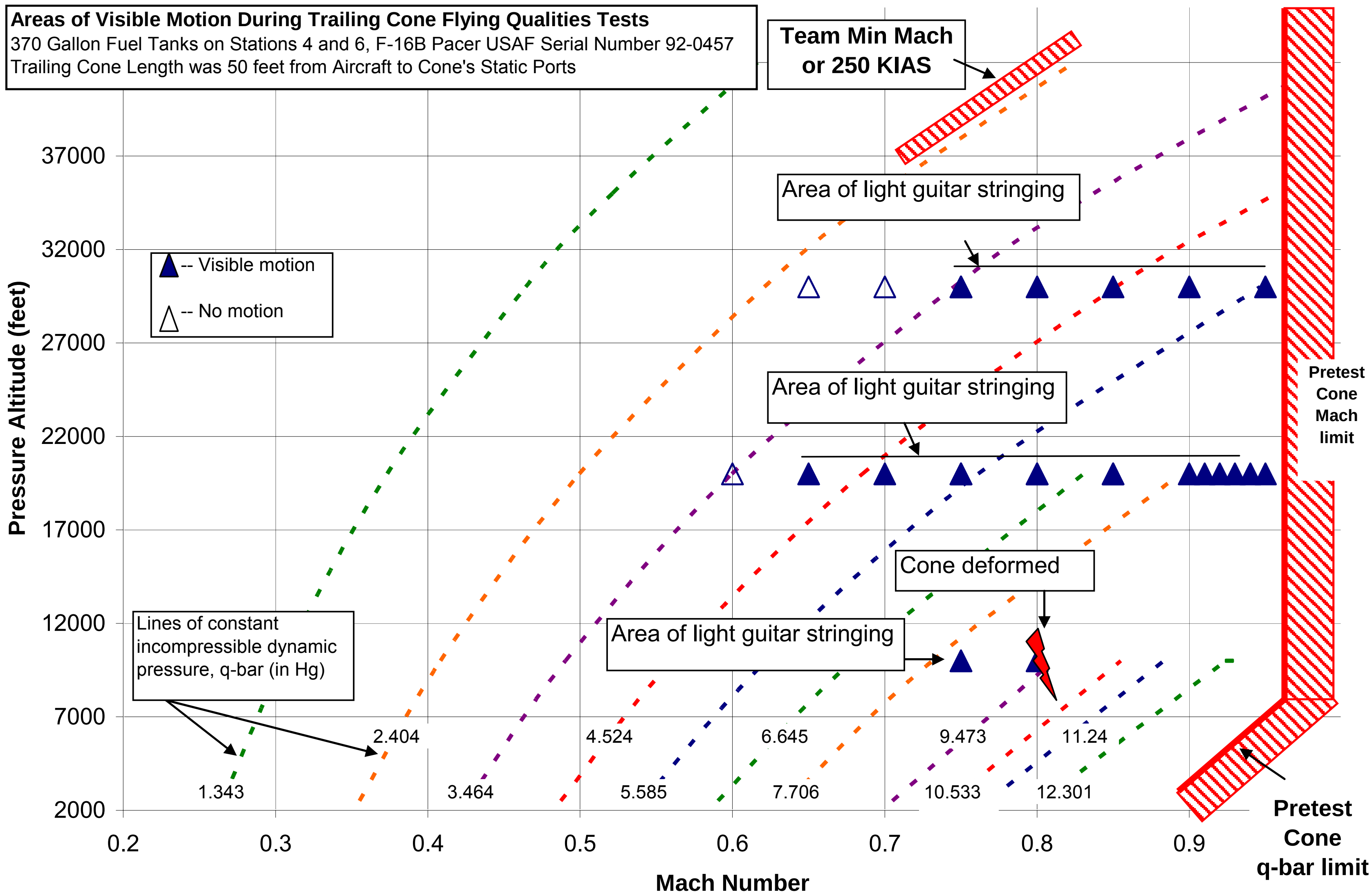

Figure D-2. Areas of Visible Motion for the 50-foot Trailing Cone System

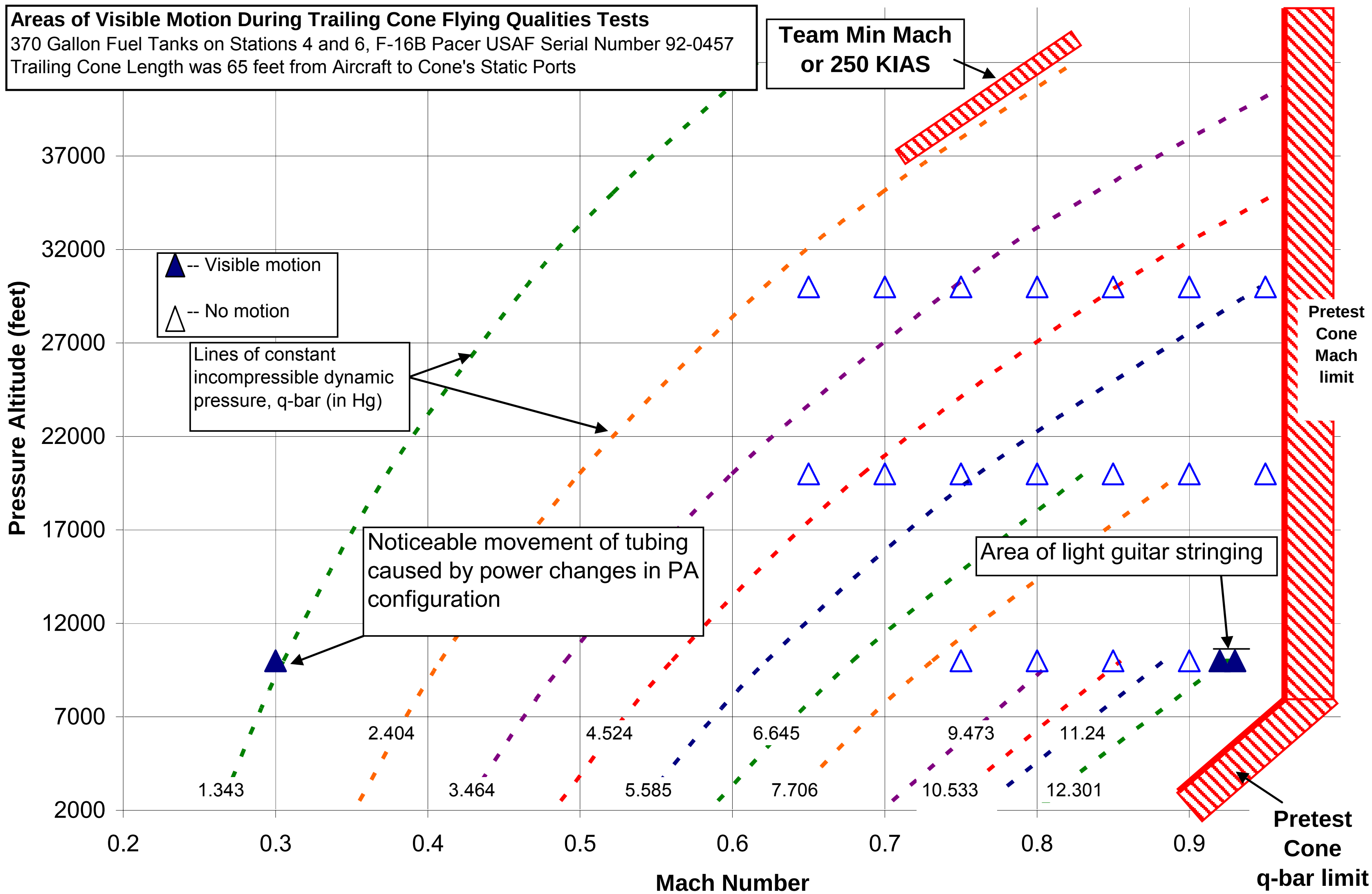

Figure D-3. Areas of Visible Motion for the 65-foot Trailing Cone System

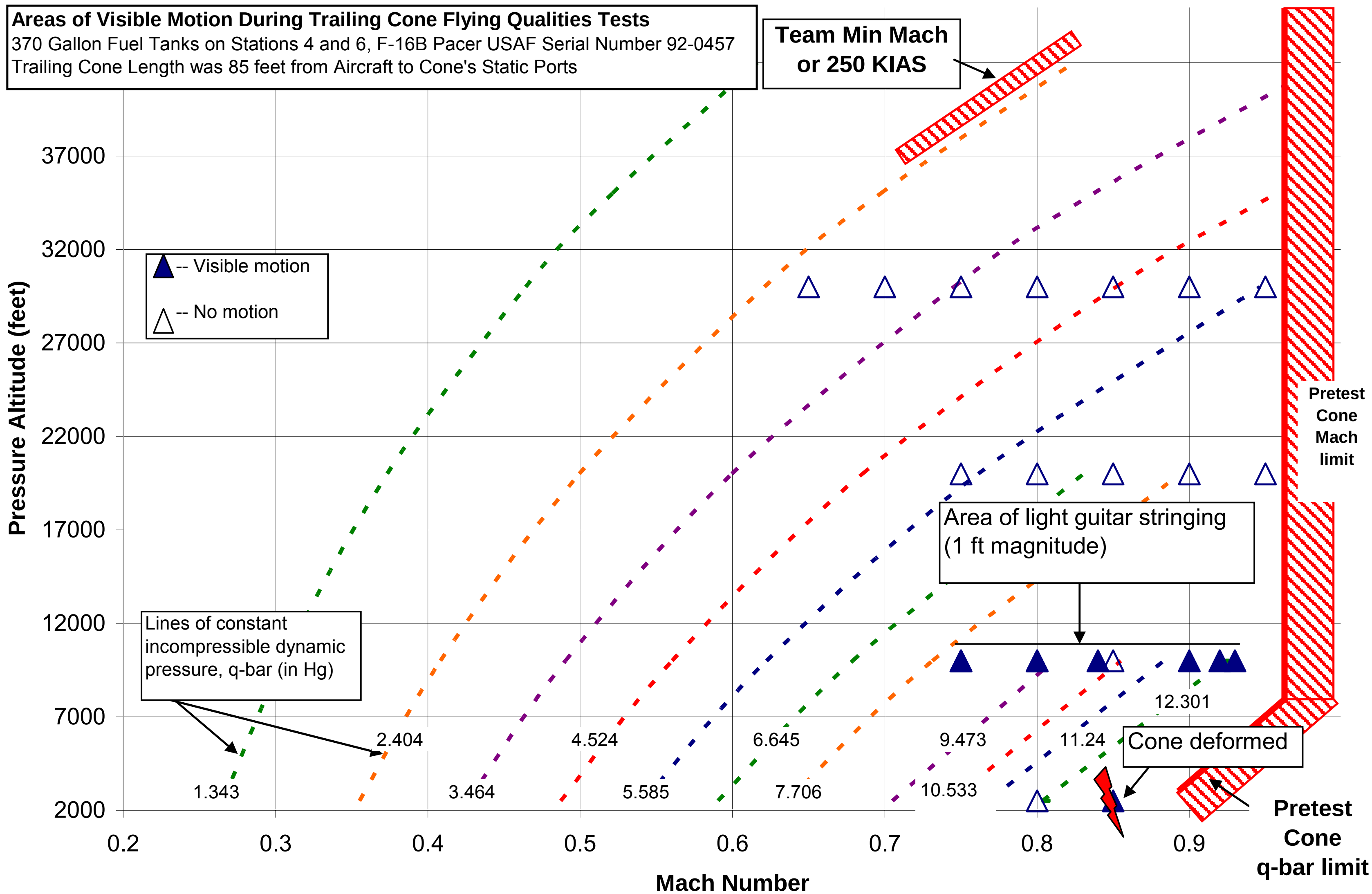

Figure D-4. Areas of Visible Motion for the 85-foot Trailing Cone System

APPENDIX E – TRAILING CONE SYSTEM POSTFLIGHT CONDITION

Table E-1. Postflight Drag Cone Measurements

System Length (ft)	Sortie	Pressure Tube		Drag Cone		Cone Number	Distance Across x-axis of drag cone base (in)	Distance Across y-axis of drag cone base (in)	Max Thickness of Cone (in) Note 1	Min Thickness of Cone (in) Note 1	Cone Weight (lbs)	Max Incomp. Dynamic Pressure (in Hg)	Cone Deformed
		P/N	S/N	P/N	S/N								
65	1,4,5	100107	035307	4152-01	034306	2	9.88	9.88	0.15	0.11	1.22	14.472	No
50	2	4152-03	041953	4152-03	041953	1	9.75	10.00	0.10	0.05	0.84	10.406	Yes
50	8,9	4152-03	041953	4152-02	041599	2	9.88	9.88	0.11	0.08	0.93	9.638	No
35	3	4152-02	041599	4152-02	041599	1	9.81	10.81	0.12	0.09	0.95	12.457	Yes
85	6	4152-01	035306	4152-01	035306	1	9.69	10.13	0.18	0.10	1.00	13.814	Yes
85	7	4152-01	035306	4152-03	041953	2	9.75	10.06	0.10	0.06	0.86	10.163	Yes

Notes: 1. Cone thickness measured between most aft and center pressure relief hole

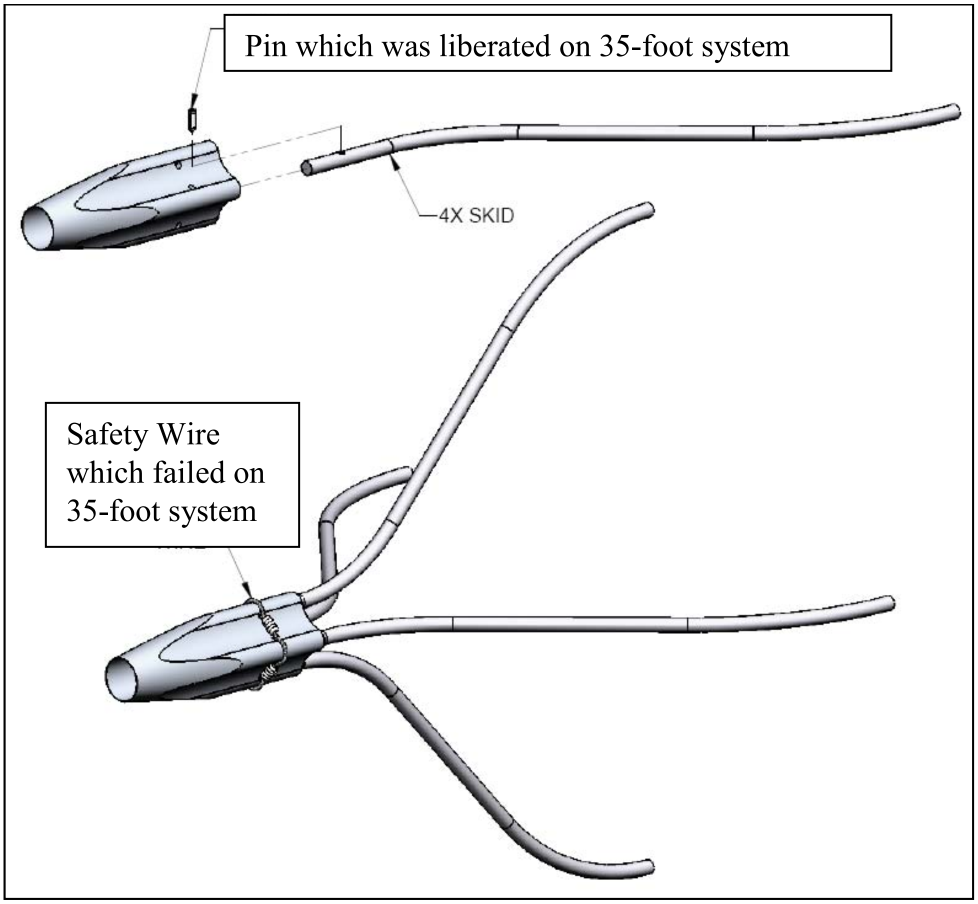

Figure E-1. Trailing Cone System Skid

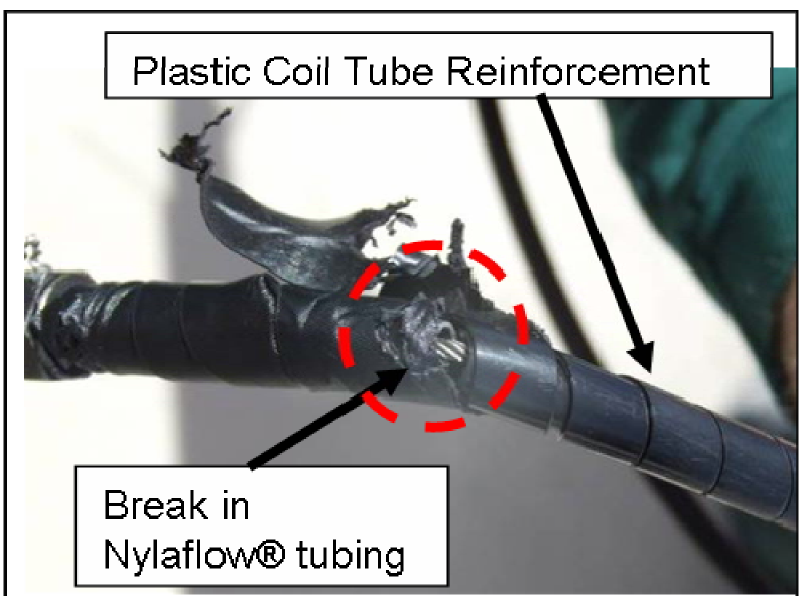

Figure E-2. Damage to Nylaflow® Tubing of 65-foot Trailing Cone

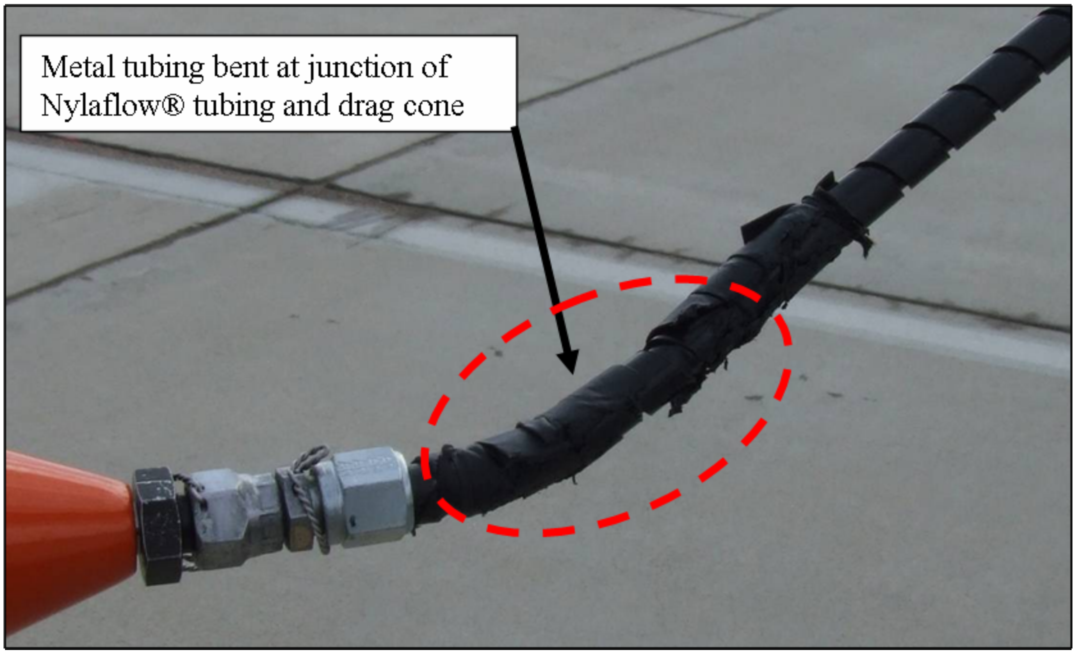

Figure E-3. 50-foot Trailing Cone System Damage After Sortie #1

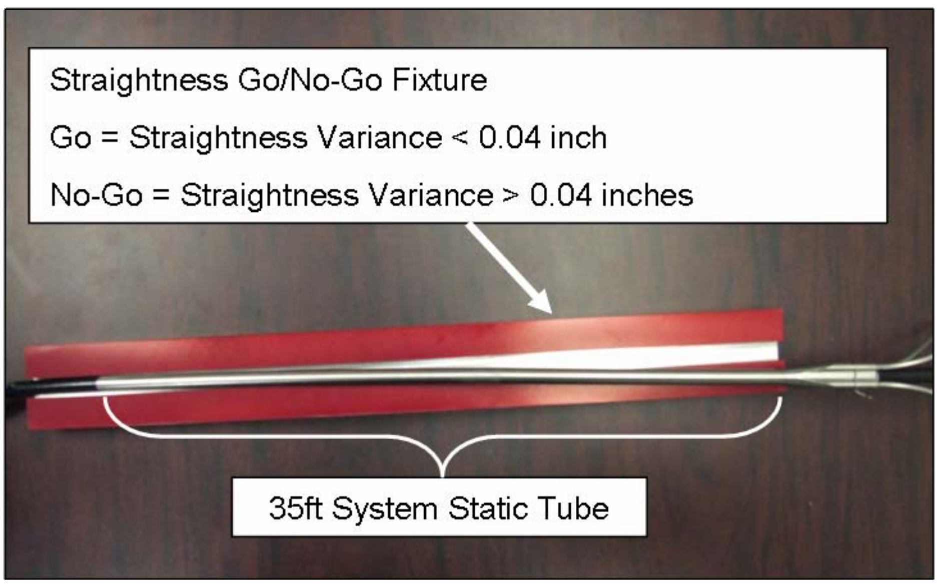

Figure E-4. 35-foot Trailing Cone System Static Tube Straightness > 0.04" After Damage During Sortie #3

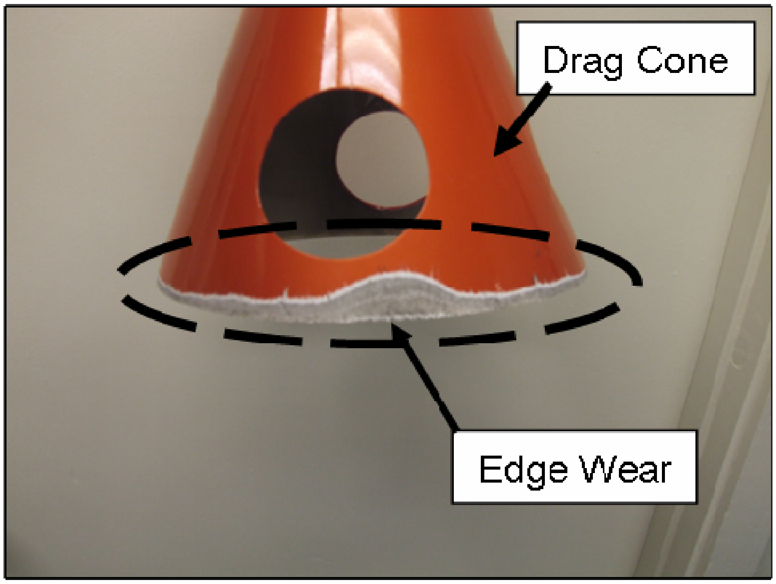

Figure E-5. Drag Cone Edge Wear

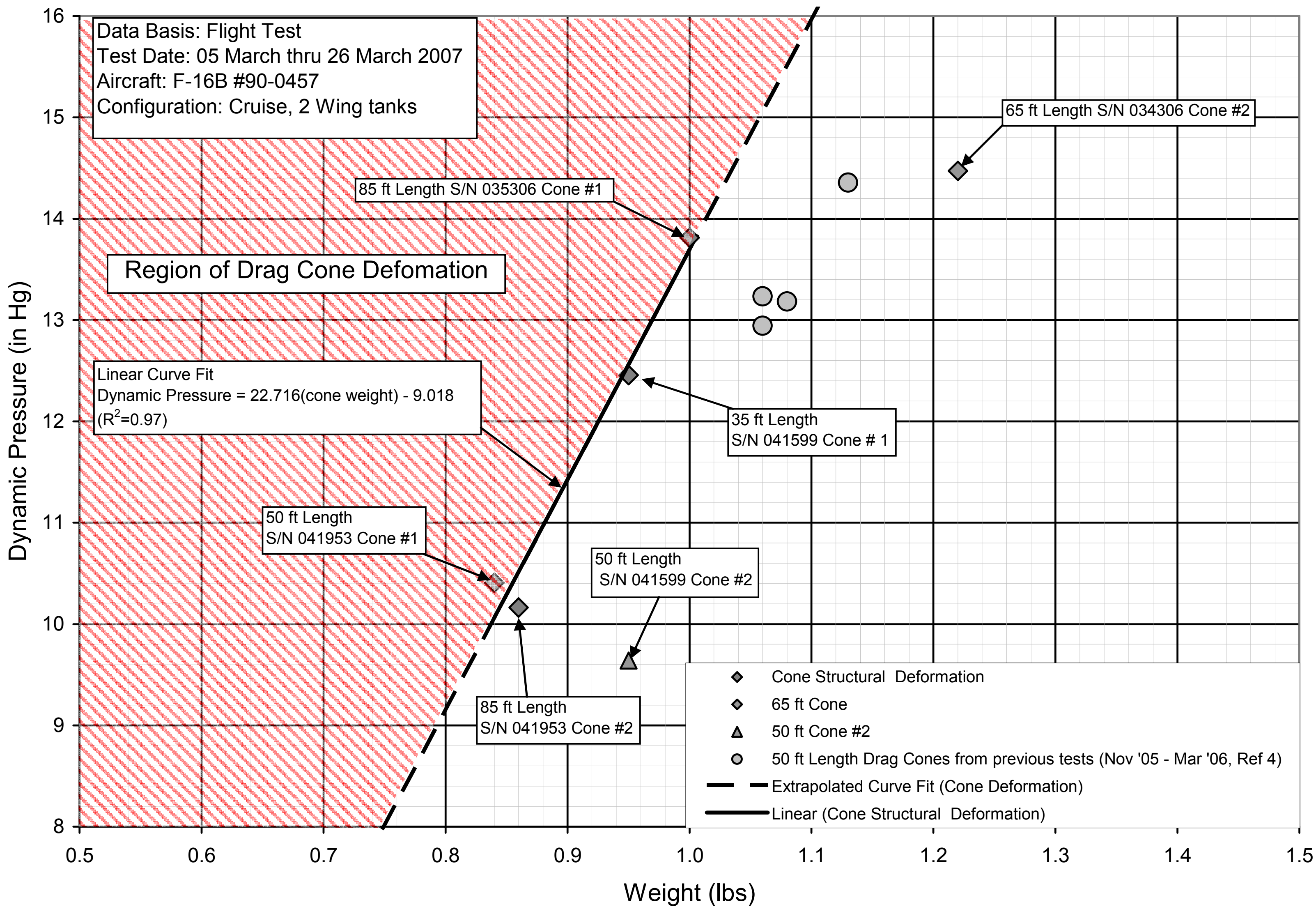

Figure E-6. Drag Cone Weight Relationship to Structural Deformations

Table E-2. Trailing Cone System Damage – Skids, Drag Cone, Pressure Tubing, and Static Tube

System Length (ft)	Sortie Number	Pressure Tube		Drag Cone		Cone #	Total Number of Sorties	Damage Observations			
		P/N	S/N	P/N	S/N			Skids (Note 1)	Max Drag Cone Edge Wear (in)	Nylaflow® Tube (Note 2)	Static Tube Straightness
65	1	100107	035307	4152-01	034306	2	1	Minor Wear	1.00	Note 3,4	<0.04”
65	4	100107	035307	4152-01	034306	2	2	Minor Wear	1.25		<0.04”
65	5	100107	035307	4152-01	034306	2	3	Minor Wear	1.50	Note 5	<0.04”
50	2	4152-03	041953	4152-03	041953	1	1	Minor Wear	0.60, Note 6	Note 7	<0.04”
50	8	4152-03	041953	4152-02	041599	2	Note 8	Minor Wear	0.50		<0.04”
50	9	4152-03	041953	4152-02	041599	2	Note 9	Minor Wear	0.50		<0.04”
35	3	4152-02	041599	4152-02	041599	1	1	Minor Wear, Note 2	0.40	Note 10	>0.04”
85	6	4152-01	035306	4152-01	035306	1	1	Significant Wear	0.86	Note 11	<0.04”
85	7	4152-01	035306	4152-03	041953	2	Note 8	Major Wear	1.5		<0.04”

Notes: 1. Levels of Skid Wear: Minor wear: ¾ or greater of skid thickness remaining; Significant wear: greater than ½ but less than ¾ of skid thickness remaining; Major wear: ¼ or less of skid thickness remaining

2. All trailing cone systems exhibited wear on Nylaflow® tubing between zero and four inches forward of the static pressure tube. Wear of Nylaflow® tubing was limited to the surface of the tubing and was a result of the angle the trailing cone system contacted the runway with the skids attached aft of the static pressure tube.

3. The 65-foot system did not have protective layer of plastic spiral wrap, shrink wrap or silicone tape on the Nylaflow® tubing forward of the drag cone on sortie #1.

4. On sortie #1 the Nylaflow® tubing of the 65ft trailing cone system was broken 3 inches forward of hose/cone interface, see figure E-4

5. The 50-foot system did not have a protective layer of plastic spiral wrap, shrink wrap or silicone tape on the Nylaflow® tubing forward of the drag cone on sortie #2.

6. Hairline cracks in the clear coat of the drag cone paint between largest and second largest pressure relief holes were observed after sortie #2. The drag cone was replaced for the following 50-foot trailing cone sorties.

7. 50-foot system metal tubing which coupled the Nylaflow® tubing and drag cone was bent on sortie # 2 and had to be repaired, see figure E-5.

8. Tube and skid portion of the system had a total of two sorties; cone had a total of one sortie.

9. Tube and skid portion of the system had a total of three sorties; cone had a total of two sorties.

10. 35-foot system lost one skid between takeoff and the test points at 10,000 ft. Nylaflow® tubing twisted during flight and plastically deformed the tubing. Plastic deformation was observed between 31.6 and 32.2 feet and 33.4 and 33.7 feet behind the pressure transmitter connection. Four inches forward of the static tube the Nylaflow® tubing was twisted and kinked beyond repair.

11. Hairline cracks in the clear coat of the drag cone paint between largest and second largest pressure relief holes were observed after sortie #6. The drag cone for the 85-foot system was replaced after sortie #6.

Table E-3. Trailing Cone System Kevlar® Temperature Profile

System Length (ft)	Sortie #	Pressure Tube		Drag Cone		Cone #	Distance Between Temperature Label and Pressure Tube & Transducer Attachment Point (ft)			Drag Cone Temperature (°F)
							10	20	30	
		P/N	S/N	P/N	S/N		Maximum Temperature Label Reading (°F)			
65	1	100107	035307	4152-01	034306	2	100	100	150	not measured
65	4	100107	035307	4152-01	034306	2	100	100	250	not measured
65	5	100107	035307	4152-01	034306	2	100	100	150	150
50	2	4152-03	041953	4152-03	041953	1	100	100	150	not measured
50	8	4152-03	041953	4152-02	041599	2	100	100	150	not measured
50	9	4152-03	041953	4152-02	041599	2	not measured	100	150	not measured
35	3	4152-02	041599	4152-02	041599	1	100	150	200	not measured
85	6	4152-01	035306	4152-01	035306	1	not measured	not measured	125	100
85	7	4152-01	035306	4152-03	041953	2	not measured	125	125	100

Maximum operating temperature of Nylaflow® tubing was 150 degrees F.
Maximum operating temperature of Kevlar® sleeve was 600 degrees F.

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APPENDIX F – DATA ANALYSIS METHODS

This section outlines the data analysis methods used to calibrate the Air Force Flight Test Center pacer aircraft, F-16B USAF serial number 92-0457. The Dual Sonix® digital pressure encoder serial number 8 was installed in pacer Pitot-static system number 1. The Dual Sonix® serial number 14 was installed in pacer Pitot-static system number 2. The two Pitot-static systems were connected to the production Pitot-static noseboom. The flight test total air temperature probe located on the left side of the fuselage was used to measure total temperature. A G-Lite differential GPS was used to measure and record earth inertial reference frame velocities and Euler angles. A fixed-length trailing cone system was anchored to the tip of the vertical stabilizer. The Paroscientific pressure transducer serial number Transmitter Serial Number 97609 was installed in the trailing cone system.

First Generation Data Processing

Data from the aircraft MIL-STD-1553 data bus, the Dual Sonix® digital pressure encoders, and the total air temperature probe was acquired by an Advanced Airborne Test Instrumentation System (AATIS) and was recorded by a Multi-Application Recorder/Reproducer System (MARS)-II recorder. Raw test data recorded on the MARS-II tape was processed into first generation engineering units data in comma separated value format using USAF Test Pilot School data reduction facilities. Data from the G-Lite differential GPS was processed into engineering units by 412TW/ENRCT personnel. Data from the trailing cone system was written to the PCMCIA flash card by a PC/104 computer. The data was time-stamped and in engineering units.

Tower Flyby Data Analysis

The tower flyby method is discussed in detail in reference 5. The flyby tower range at Edwards Air Force Base was used to calibrate the test aircraft.

Ambient air pressure, pressure altitude, and temperature were hand-recorded every four minutes starting 30 minutes prior to the first tower flyby pass and ending 30 minutes after the final flyby pass. The ambient air pressure was recorded from both the Setra and Druck pressure transducers in inches of Hg. Pressure altitude was recorded in feet from the NovaLynx pressure transducer. Pressure altitude and temperature were also recorded from the base weather service.

The data recorded every four minutes was modeled by fitting a line of least squares. The model curves for pressure altitude and ambient air temperature at the zero grid line were used to calculate the values of pressure altitude and temperature at the time the aircraft passed by the tower. The model curves were represented as functions of time:

$$H_{\text{ZGL}} = f(\text{time}) \tag{B1}$$

$$T_{\text{ZGL}} = g(\text{time}) \tag{B2}$$

where H_{ZGL} and T_{aZGL} are the pressure altitudes and temperatures at the elevation of the zero grid line.

The grid reading recorded by the observer was converted into a tapeline altitude difference between the zero grid line and the aircraft.

$$\Delta h_{tower} = 31.48 \cdot GR \tag{B3}$$

where GR is the grid reading. The resultant Δh_{tower} is in units of feet of geometric, or tapeline, altitude above the zero grid line.

The tapeline altitude above ground level was calculated with the grid readings and the ground elevation of the zero grid line of the flyby tower.

$$H_{AGL\,tower} = \Delta h_{tower} + 34.26 \tag{B4}$$

Video recordings of the grid reading were taken and the tapeline altitude, $H_{AGLvideo}$ based on video data, was recorded. Radar altimeter readout of the test aircraft for each pass were recorded, $H_{AGL\_Ralt.}$ The G-Lite GPS altitude above ground level, $H_{AGL\_G\text{-}Lite}$ was also recorded for each pass.

The standard day temperature (Kelvin) was calculated using the standard day temperature profile (reference 6) and the pressure altitude at the zero grid line.

$$T_{a_{SD}} = T_{a_{SL}} - 0.0019812 \cdot H_{ZGL} \tag{B5}$$

where T_{aSL} is the temperature at sea level on a standard day (T_{aSL} = 288.15 K).

The difference in tapeline altitude, Δh, was converted to a difference in pressure altitude by correcting for non-standard day temperature.

$$\Delta H = \Delta h \cdot \frac{T_{a_{SD}}}{T_{a_{ZGL}}} \tag{B6}$$

where ΔH is the difference in pressure altitude between the zero grid line and the aircraft.

The pressure altitude at the location of the aircraft was calculated by adding ΔH to the pressure altitude at the zero grid line.

$$H_c = H_{ZGL} + \Delta H \tag{B7}$$

The ambient air pressure corresponding to H_c was calculated using the equation from the standard atmosphere for altitudes below 36,089 feet.

$$P_{\mathrm{a}} = P_{\mathrm{a_{SL}}}(1 - 6.87558\times10^{-6}\cdot H_{\mathrm{c}})^{5.25591} \tag{B8}$$

The static air pressures of the trailing cone were corrected for instrument errors. The instrument error corrections for the Paroscientific pressure transducer were determined from a laboratory calibration.

$$P_{\mathrm{sic\_cone}} = P_{\mathrm{s\_cone}} - 0.0009983\ \mathrm{InHg} \tag{B7}$$

The trailing cone's pressure altitude was then calculated.

$$H_{\mathrm{ic_{cone}}} = -145442\times[(P_{\mathrm{S_{cone}}}/P_{\mathrm{a_{SL}}})^{0.190262} - 1] \tag{B8}$$

The trailing cone's static source error correction ΔH_{pc_cone} was the difference between the instrument corrected trailing cone pressure altitude and test aircraft ambient air pressure

$$\Delta H_{\mathrm{pc_{cone}}} = H_c - H_{\mathrm{ic_{cone}}} \tag{B9}$$

The trailing cone's static source error correction was plotted against instrument-corrected equivalent airspeed, $V_{e_{ic}}$. The instrument-corrected equivalent airspeed for each test point was calculated using instrument-corrected total and static pressures from the pacer noseboom system. The pressures were not corrected for noseboom position errors.

$$V_{\mathrm{e_{ic}}} = \sqrt{\left(\frac{1}{\rho_{\mathrm{SL}}}\right)7P_s\left[\left(\frac{q_{cic}}{P_s}+1\right)^{2/7}-1\right]} \tag{B11}$$

where ρ_{SL} is the density at sea level on a standard day (ρ_{SL} = 0.002377 slugs/ft^3) and the instrument-corrected compressible dynamic pressure, q_{cic}, was equal to the difference between the instrument-corrected total and static pressures.

$$q_{cic} = P_t - P_s \tag{B12}$$

The static source error correction coefficient for the trailing cone system was equal to the difference between the ambient air pressure and the instrument-corrected air pressure, all divided by the instrument-corrected static pressure.

$$\frac{\Delta P_{\mathrm{pc,cone}}}{P_{\mathrm{sic,cone}}} = \frac{P_{\mathrm{a}} - P_{\mathrm{sic,cone}}}{P_{\mathrm{ic,cone}}} \tag{B13}$$

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APPENDIX G – TOWER FLYBY RESULTS

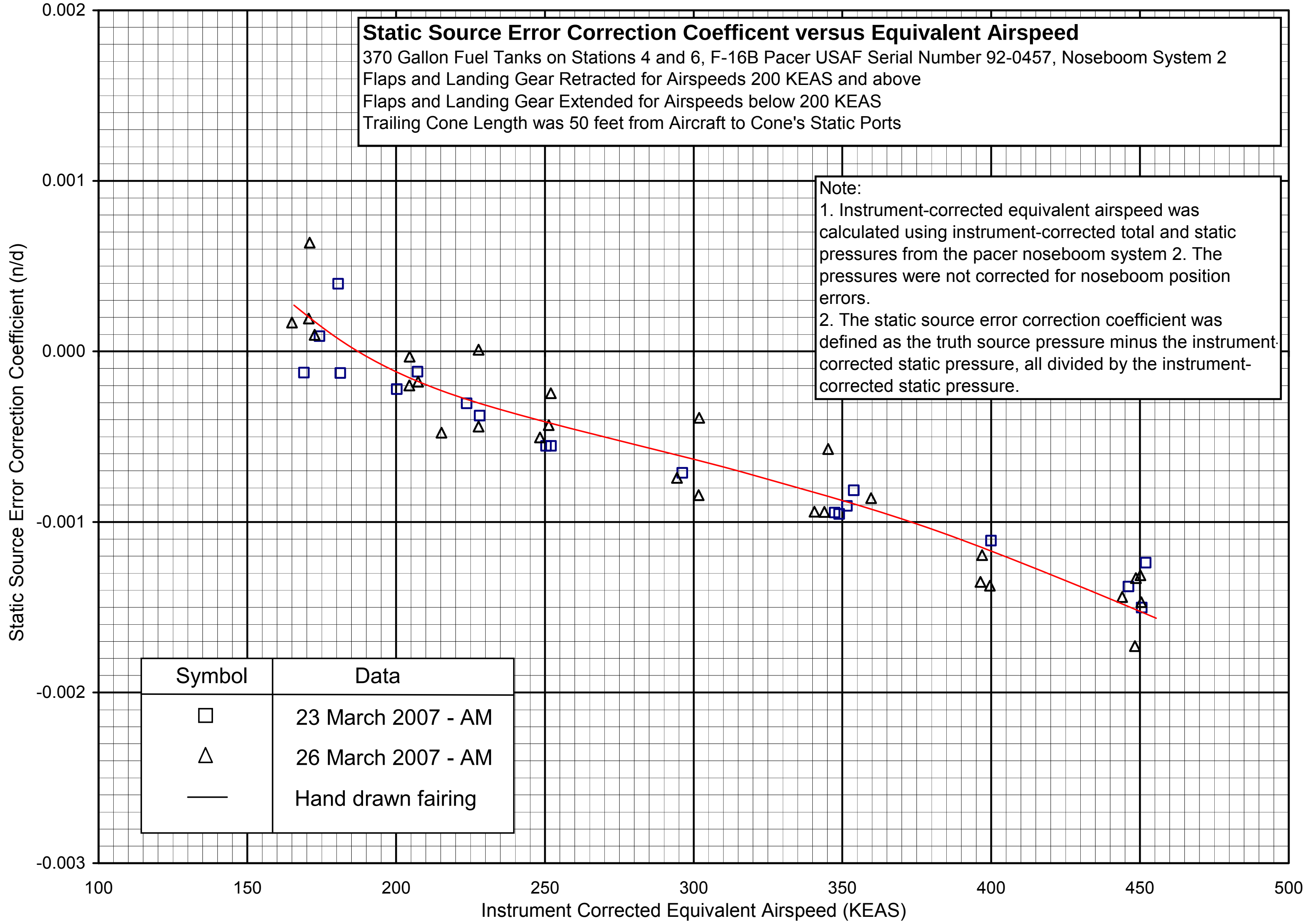

Figure G-1. 50-foot Trailing Cone Static Source Error Correction Coefficient

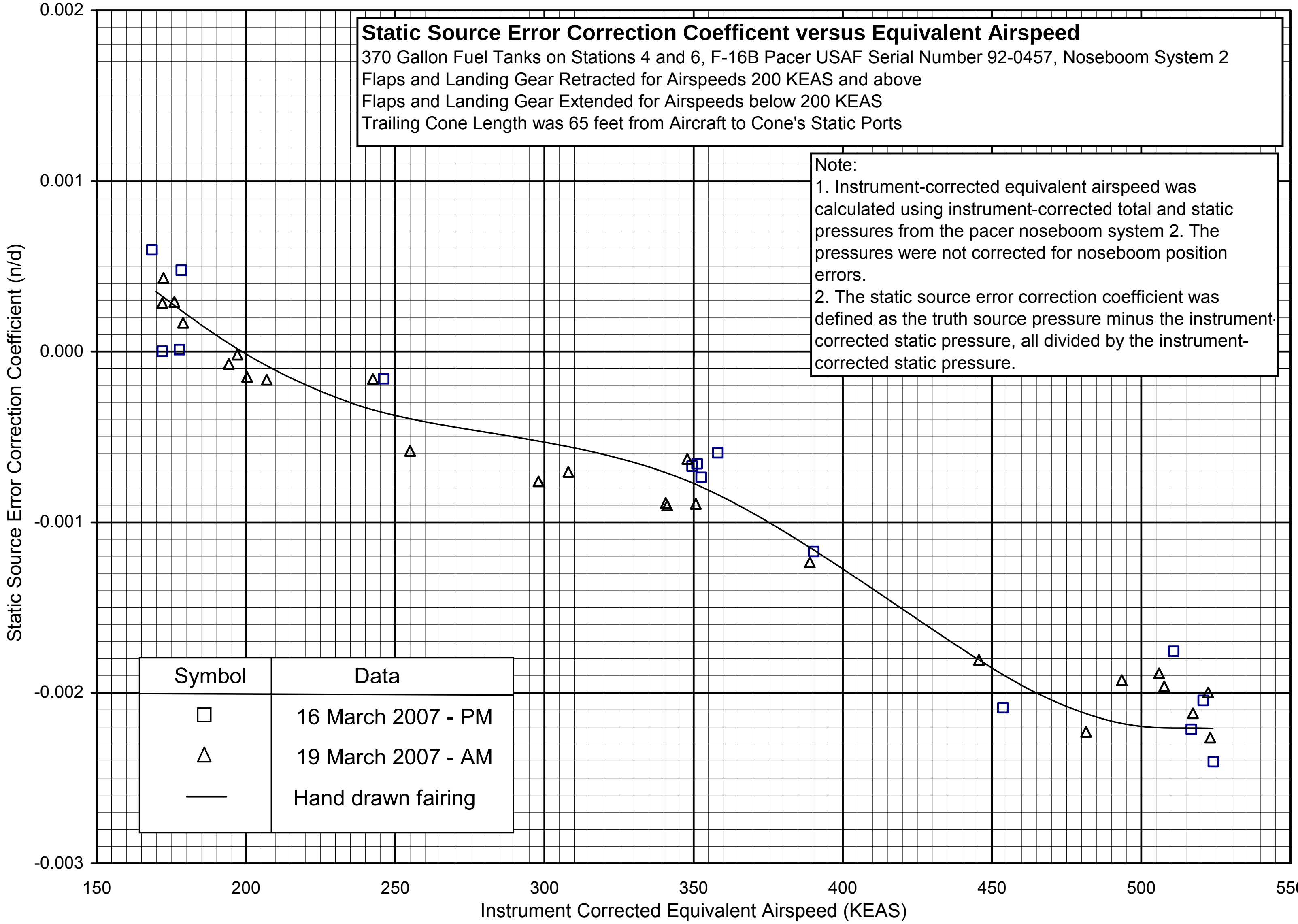

Figure G-2. 65-foot Trailing Cone Static Source Error Correction Coefficient

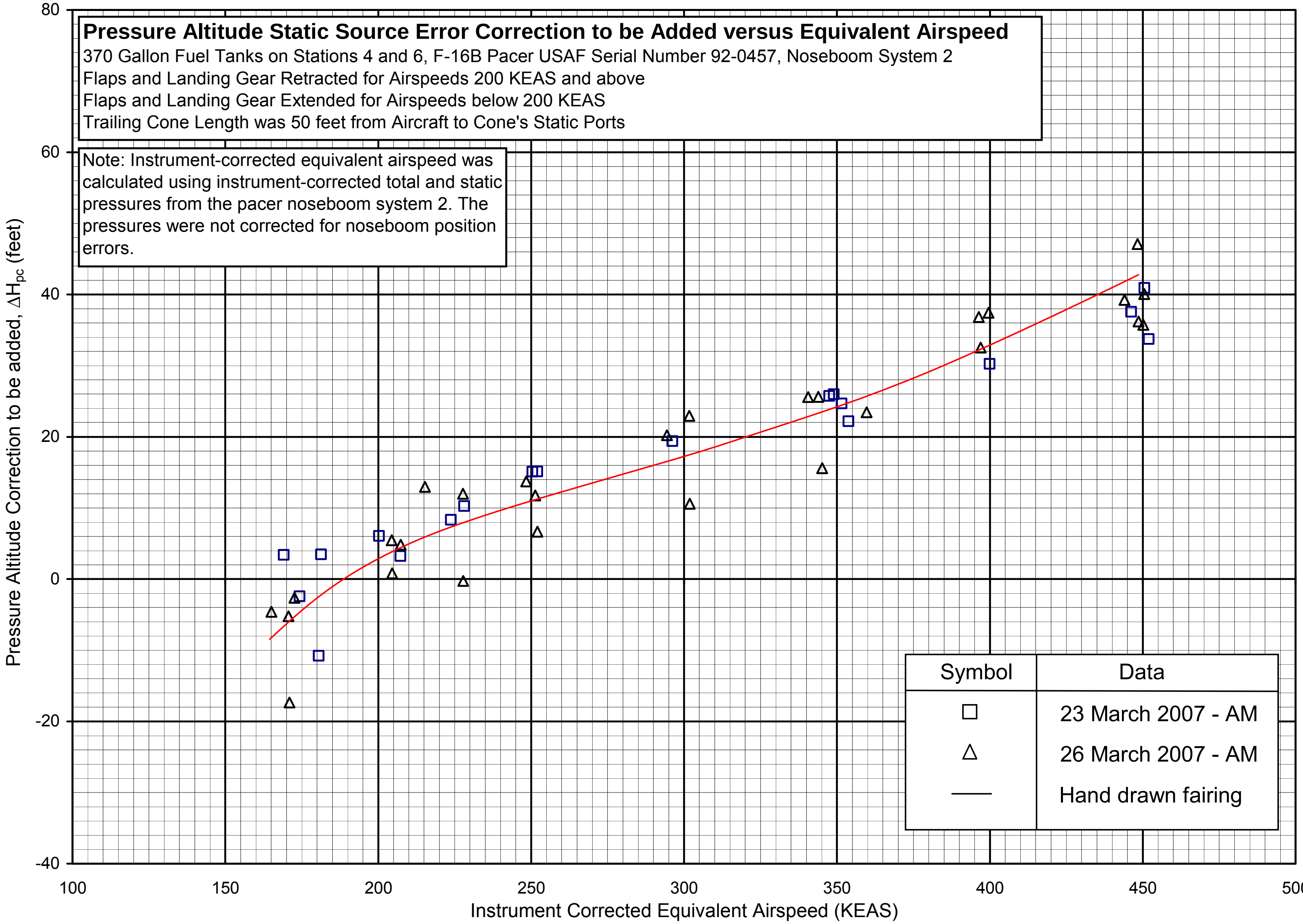

Figure G-3. 50-foot Trailing Cone Static Source Error Correction - Pressure Altitude

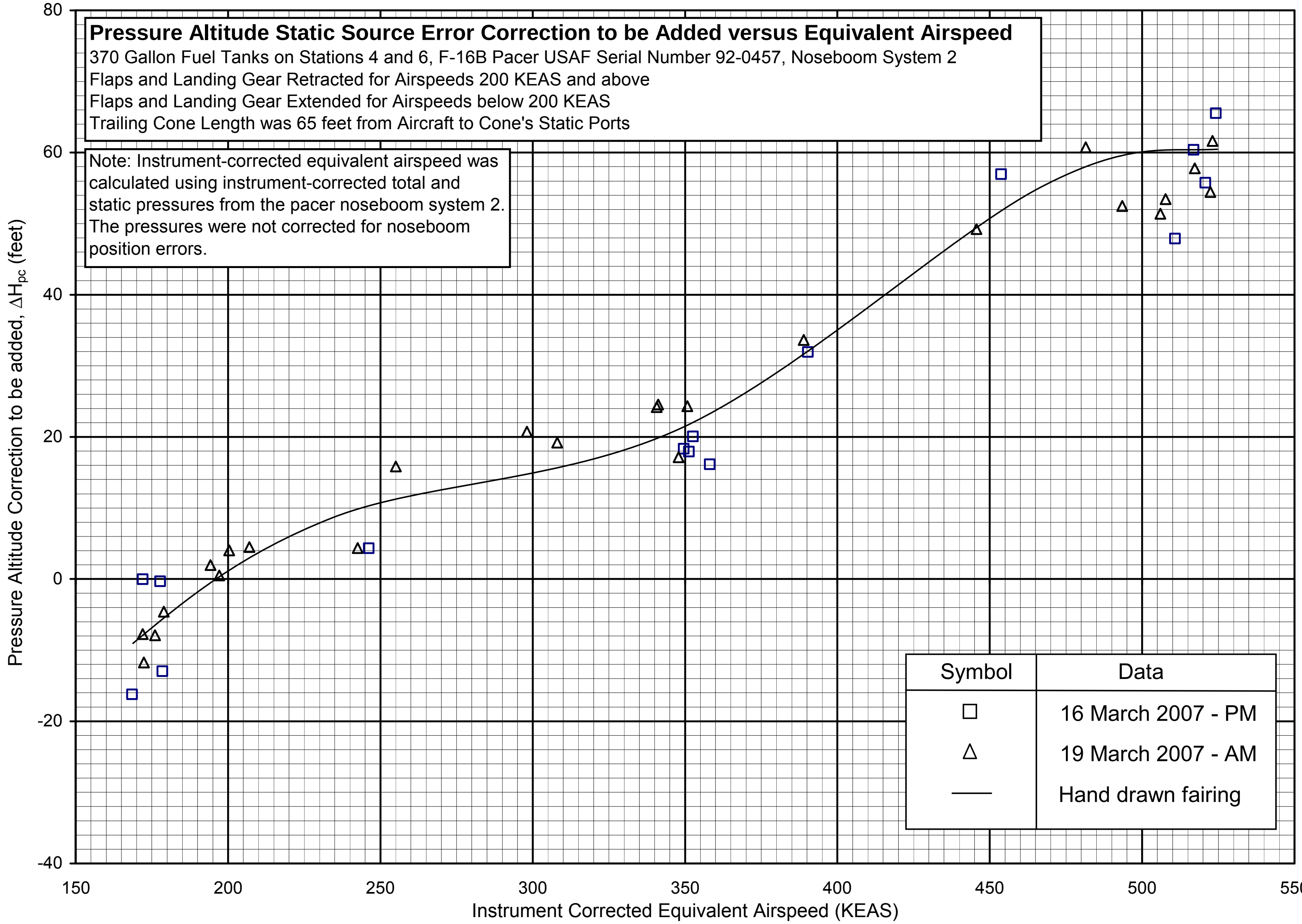

Figure G-4. 65-foot Trailing Cone Static Source Error Correction - Pressure Altitude

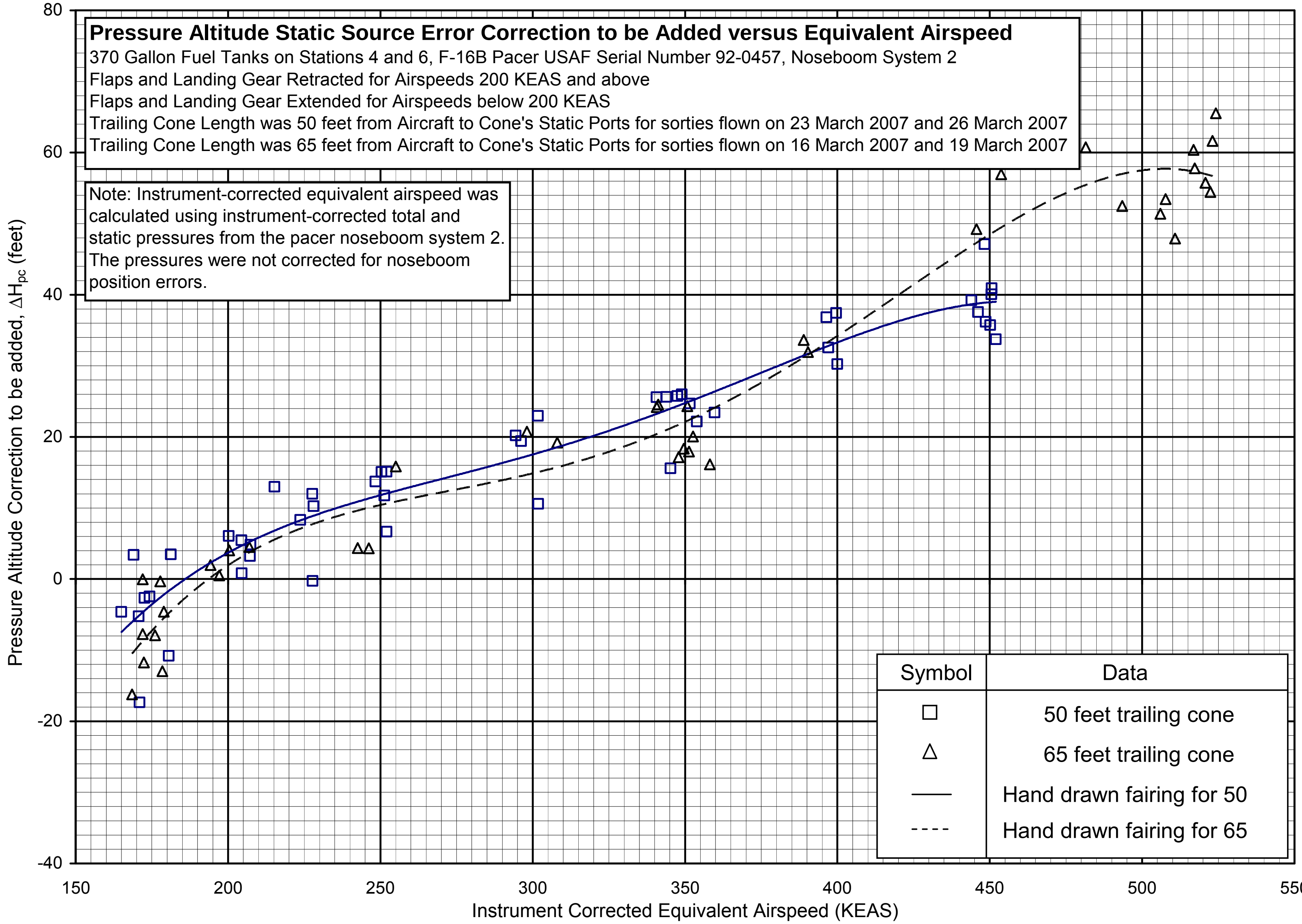

Figure G-5. Comparison of 50-foot and 65-foot Trailing Cone Static Source Error Correction - Pressure Altitude

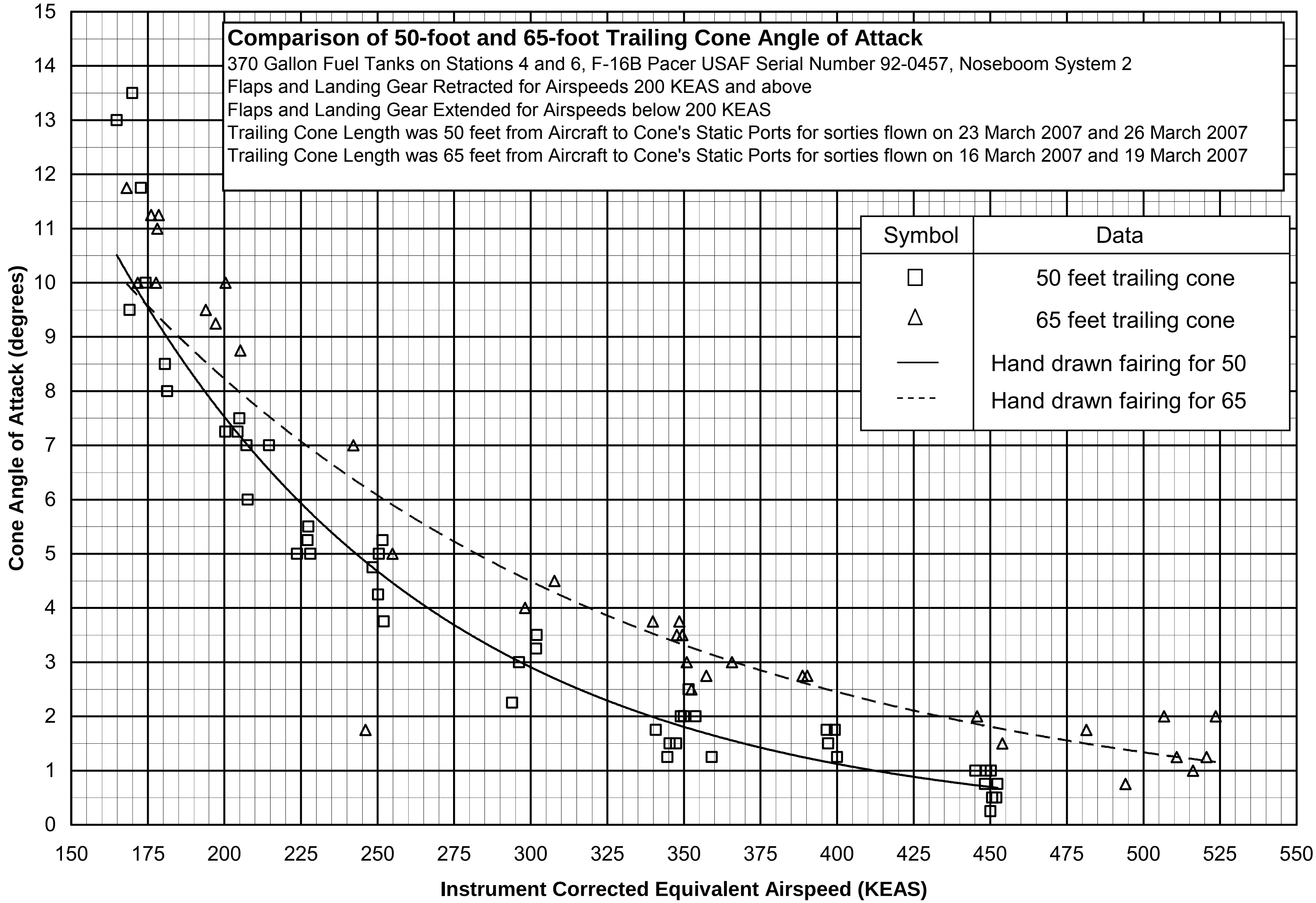

Figure G-6. Comparison of 50-foot and 65-foot Trailing Cone Angle of Attack

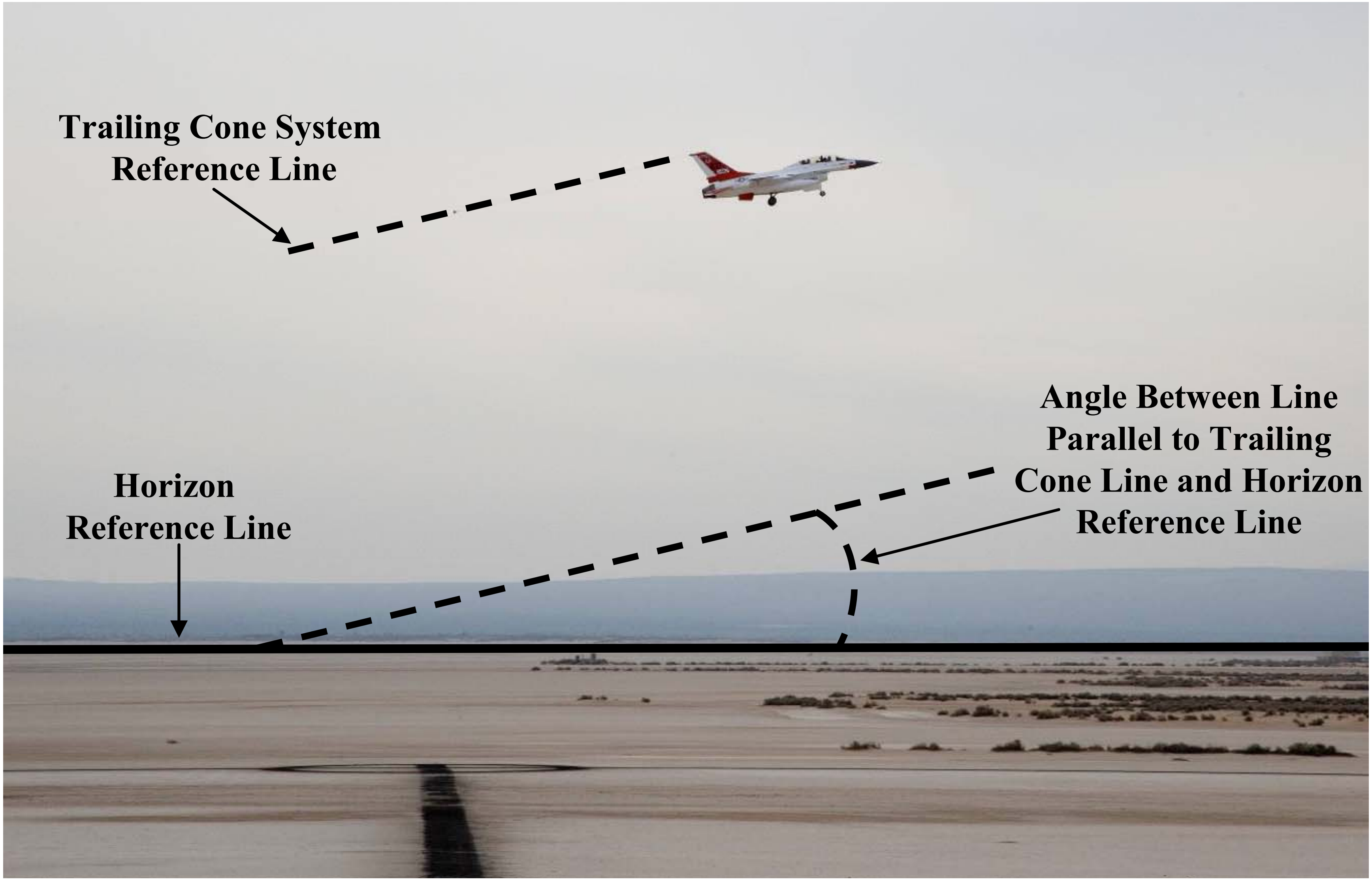

Figure G-7. Method Used to Determine Trailing Cone Angle of Attack

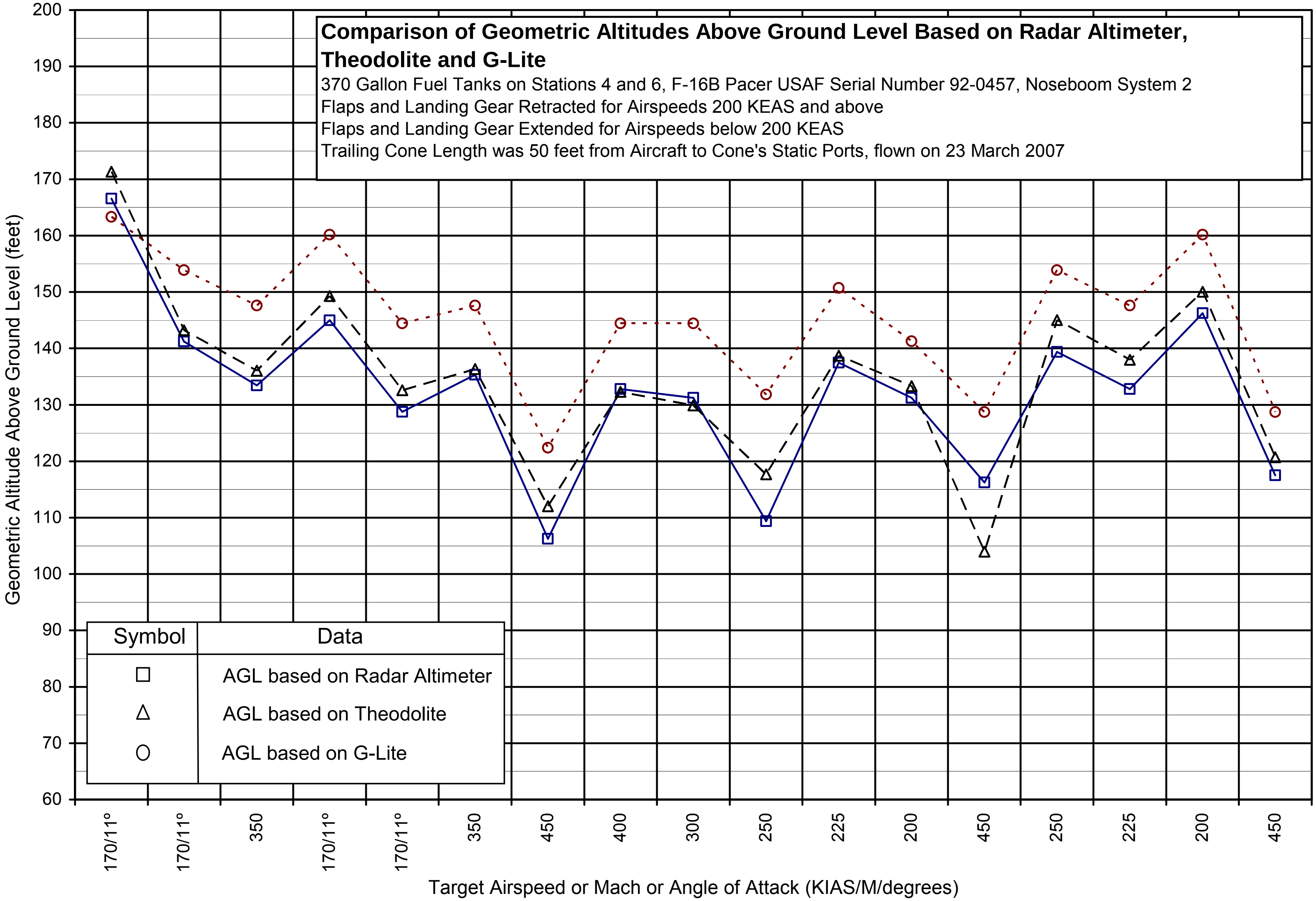

Figure G-8. Comparison of Above Ground Level Altitude – 50-foot Tower Flyby #1

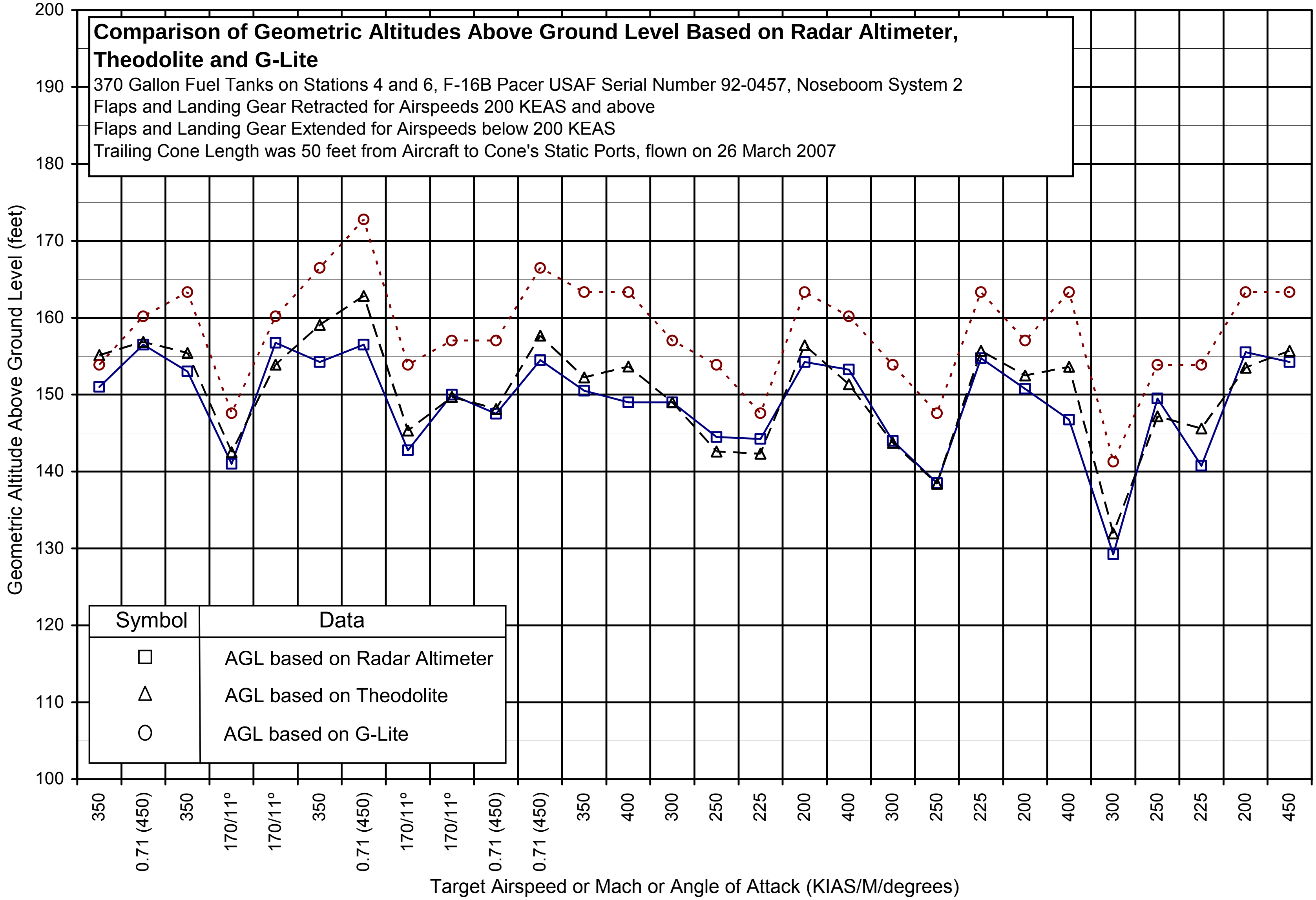

Figure G-9. Comparison of Above Ground Level Altitude – 50-foot Tower Flyby #2

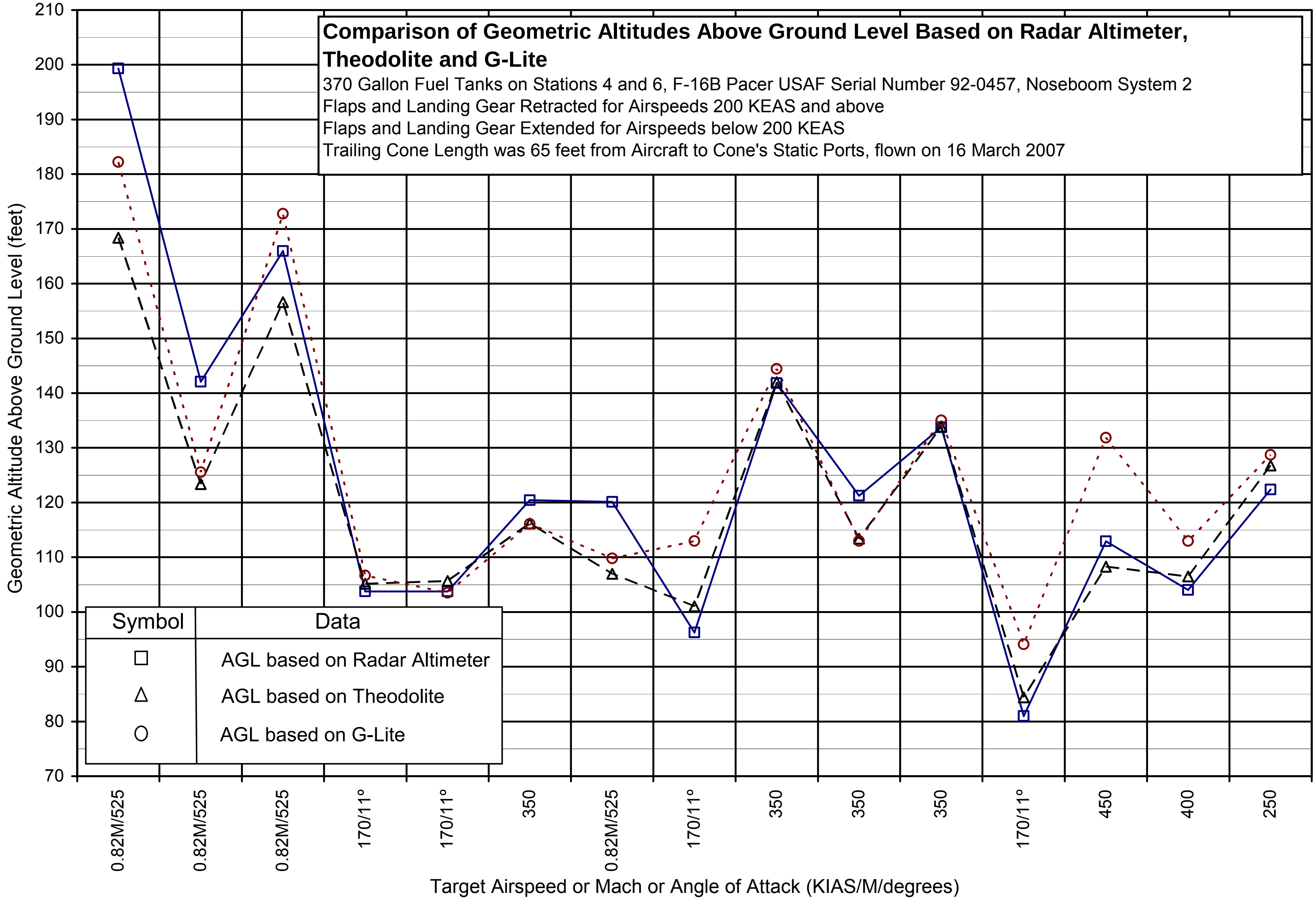

Figure G-10. Comparison of Above Ground Level Altitude – 65-foot Tower Flyby #1

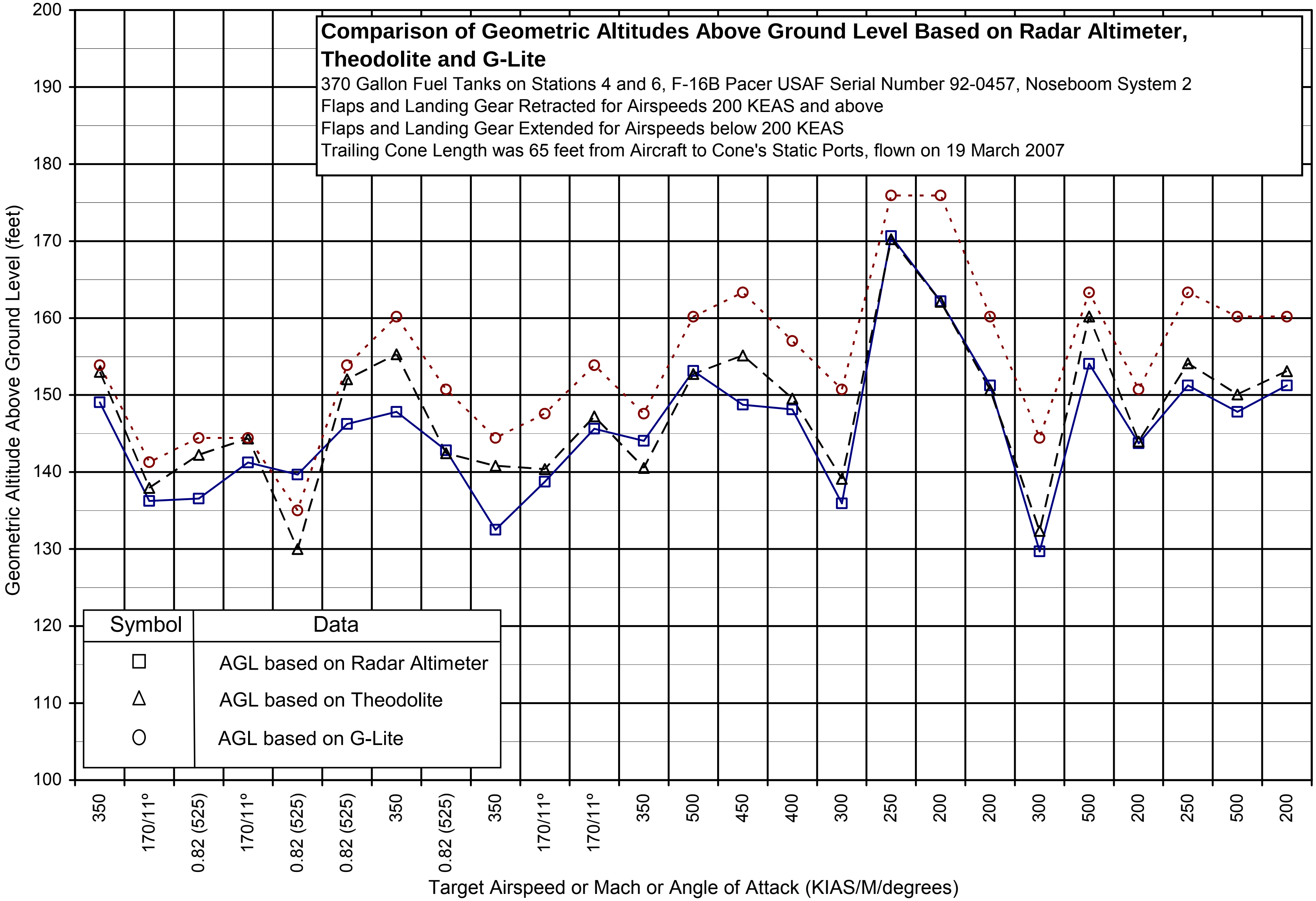

Figure G-11. Comparison of Above Ground Level Altitude – 65-foot Tower Flyby #2

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APPENDIX H – LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation	Definition	Units
AATIS	Advanced Airborne Test Instrumentation System	---
AFFTC	Air Force Flight Test Center	---
AGL	above ground level	feet
CADC	Central Air Data Computer	---
CLETIS	cone length extension tube investigative study	---
DAS	data acquisition system	---
EU	engineering units	---
F	Fahrenheit	degrees
FCP	front cockpit	---
FQ	flying qualities	---
GPS	global positioning system	---
GR	theodolite grid reading recorded in the flyby tower	---
$H_{AGL\_G\text{-}Lite}$	tapeline altitude based on G-Lite data	feet
H_{AGL_Ralt}	tapeline altitude based on radar altimeter data	feet
$H_{AGLtower}$	tapeline altitude above ground level	feet
$H_{AGLvideo}$	tapeline altitude based on video data	feet
H_{ZGL}	pressure altitude model curve	feet
H_{c}	pressure altitude at the location of the aircraft	feet
in Hg	inches of Mercury (unit of pressure)	in Hg
KCAS	knots calibrated airspeed	knots
KEAS	knots equivalent airspeed	knots
MARS-II	Multi-Application Recorder/Reproducer	---
P/N	part number	---
P_{a}	ambient air pressure	in Hg
PA	pressure altitude	feet
P_{aSL}	ambient air pressure at sea level	in Hg
PCM	pulse code modulation	---
P_s	instrument-corrected static pressure	in Hg
$P_{\mathrm{s,cone}}$	trailing cone static pressure	in Hg
$P_{\mathrm{sic,cone}}$	trailing cone static pressure corrected for instrument errors	in Hg
P_t	instrument-corrected total pressure	in Hg

Abbreviation	Definition	Units
q_{cic}	instrument-corrected compressible dynamic pressure	in Hg
RCP	rear cockpit	---
rpm	revolutions per minute	---
S/N	serial number	---
SPCM	small pulse code modulation	---
SSEC	static source error correction	---
T_{aSD}	standard day temperature	degrees
T_{aSL}	standard day temperature at sea level	degrees
T_{aZGL}	ambient air temperature	degrees
TFB	tower flyby	---
$V_{e_{ic}}$	instrument-corrected equivalent airspeed	knots
Δh	difference in tapeline altitude	feet
ΔH	difference in pressure altitude	feet
Δh_{tower}	tapeline altitude above the zero grid line	feet
ΔH_{ic_cone}	trailing cone pressure altitude	---
ΔH_{pc_cone}	trailing cone static source error correction	---
ΔH_{pc}	pressure altitude correction	feet
ΔP_{pc}	error correction to add to the trailing cone static pressure	feet
ρ_{SL}	standard day sea level density	slugs/ft^3

APPENDIX I – TPS LESSONS LEARNED

Preflight/Ground ops

- During flight briefs, pilot and ground crew need to brief procedures for “bad cone” so pilots is aware this call may be made and has thought through go/no-go criteria during longer takeoff rolls
- Callsigns for all test agencies need to be clear and unambiguous; ie. CLETIS Mobile or CLETIS flyby
- The Nylaflow® tubing immediately forward of the cone will be double-wrapped by SI during preflight to provide extra resistance to damage
- HAVE CLETIS Mobile crew needs to pick up crew chief to act as primary marshaller when ready to taxi and for RTB.
- Ground familiarization was essential to coordination of ground personnel/ops prior to first flight. This included operation of the DAS, rolling/unrolling/stowing of cone systems, familiarization with danger areas of the F-16 for ground ops and a face to face briefing with SI and crew chiefs.
- Everyone on the test team needs to have a flightline driver’s license. Syllabus flights and school assignments continue during TMP flights so we never knew who would be tasked for ground duties.
- Ensure IPs are thoroughly briefed on the test and operation of the test equipment so they can be incorporated as a part of the test team.

Takeoff/Landing

- Coordinate with tower for takeoff on mission frequency so the cone flying call can be heard without being stepped on by normal tower frequency calls.
- Even if previously coordinately for taxi to the end of the runway, if Bravo can be made the test crew should taxi clear at Bravo to minimize cone damage. Or follow procedures in the test plan to stop on the runway and have the ground crew enter the runway to stow the cone.
- Tower was difficult to reach on its published alternate frequency of 236.6 MHz. The correct alternate frequency is actually 353.6 MHz. VHF mission frequency between chase and test proved invaluable for test conduct.
- The planned communication procedures were too verbose and could be abbreviated to simple calls such as “Cone stable” from chase in between test points.
- Takeoff acceleration of 2 percent rpm may be excessive. A slower acceleration may be required if the break in the plastic tubing could be attributed to the impacts seen on takeoff. Also the cone flying may have been premature since secondary cone hits occurred after the call.
- Takeoff on the new tower frequency and conduct all operations on VHF mission frequency. Delay the cone flying call until cone flight is well established.

Cone Flying Qualities Sorties

- Test team should consider not exceeding q-bar of 10K and 0.85 Mach number for remaining sorties due to cone anomalies at these points.
- Cone flying qualities descriptors can be improved. The cone tubing "guitar stringing" characteristics were observed frequently during testing and could be included as an evaluation characteristic.
- During chase operations it would be easier to UHF mission with tower for the launch. Also a plain English discussion of what is about to occur both on and off the runway during the unique CLETIS airborne pickup proved effective. This discussion should take place both on the phone prior to step and on the radios in EOR.
- Examine the structural integrity of each cone after delivery. A relationship between cone weight and maximum incompressible dynamic pressure before deformation was determined for the cones tested.

Tower Flyby

- VHF mission is the best means for test team coordination during the tower flyby.
- The tower flyby FTE should provide the test aircrew with a "Good cone" call to inform the crew that cone was still intact and not deformed. This becomes particularly important following higher speeds, i.e. higher q-bar, points.
- Conversely, the test aircraft should provide feedback on data quality such as "On speed and on the flyby line" or if off parameters the test aircraft should provide specific data such as "5 knots hot and 10 feet left."
- Both the tower personnel and test aircrew should be keenly aware of fuel in order to prioritize remaining points to fly or repeat. The decision on priority data points should remain with the tower personnel since it is they who can assess confidence in the truth altitude readings associated with the run.
- Flyby tower FTE acted as TC during the sortie as he was in the same location as the customer. This needs to be clear prior to sortie execution.
- Establish comm for good pass; ie. Test aircraft – "Stable, on centerline"
Flyby tower – "Good cone, on altitude"
- Take video recording of the theodolite readings as a backup to handwritten data. The recordings proved to be useful in verifying accuracy of possible erroneous theodolite readings. The setup of the video camera should be the same for every sortie, that is, the location, height and zoom of the camera
- Chase operations using the UHF mission with tower made launch procedures simple and streamlined.
- Have "CLETIS CONTROL" backup radio procedures with test aircraft to ensure all radio calls are made IAW 11-1

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